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TECHNICAL REPORT NO. 3-666

PERFORMANCE OF SOILS UNDER TIRE LOADS

Report 5

DEVELOPMENT AND EVALUATION OF MOBILITY NUMBERS FOR COARSE-GRAINED SOILS

by

A. J. Green

July 1967

Sponsored by

U. S. Army Materiel Command

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Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

FOREWORD

These tests were conducted at the U. S. Army Engineer Waterways Experiment Station (WES) as a part of the vehicle mobility research program under DA Project 1-V-0-21701-A-046, "Trafficability and Mobility Research," Task 1-V-0-21701-A-046-03, "Mobility Fundamentals and Model Studies," under the sponsorship and guidance of the Directorate of Research and Development, U. S. Army Materiel Command.

The tests were performed by personnel of the Mobility Research Branch, Mobility and Environmental Division, WES, during the period November 1963 to March 1965 under the general supervision of Messrs. W. G. Shockley and S. J. Knight, and under the direct supervision of Dr. D. R. Freitag. Actively engaged in the study were Messrs. A. J. Green, J. C. Chang, N. R. Murphy, Jr., M. D. Beasley, and H. B. Boyd. The data were analyzed by Messrs. Green and Murphy. This report was prepared by Mr. Green.

COL Alex G. Sutton, Jr., CE, and COL John R. Oswalt, Jr., CE, were Directors of WES during this study and preparation of this report. Mr. J. B. Tiffany was Technical Director.

CONTENTS

CONVERSION FACTORS, METRIC TO BRITISH UNITS OF MEASUREMENT

Metric units of measurement used in this report can be converted to British units as follows:

Multiply	By	To Obtain
meters	3.2808	feet
centimeters	0.3937	inches
millimeters	0.03937	inches
kilonewtons	225.0	tons
newtons	0.2250	pounds
newtons per square centimeter	1.4503	pounds per square inch
grams per cubic centimeter	62.4300	pounds per cubic foot
kilograms	2.2045	pounds
meter-newtons	3.7382	foot-pounds

SUMMARY

This study examined the effects of tire deflection, tire geometry, wheel load, and soil strength on the performance of coarse-grained soils subjected to moving tire loads. Mathematical expressions were developed that combine the independent tire-soil and system parameters and relate them to the performance coefficients.

A combination of independent parameters, $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$, was developed from single-wheel laboratory tests. This expression, referred to as the sand mobility number, is shown to account for the combined effects of soil strength (G), tire section width and diameter (b and d, respectively), wheel load (W), and tire deflection (δ/h) on wheel performance as measured by the performance coefficients.

A multiple-pass analysis was conducted to illustrate that performance on the second and third passes also could be related to the sand mobility number, although the relation was not the same as that for the first pass. It was shown in a similar fashion that the performance of vehicles on coarse-grained soils could be predicted using a relation based on the sand mobility number.

PERFORMANCE OF SOILS UNDER TIRE LOADS

DEVELOPMENT AND EVALUATION OF MOBILITY NUMBERS FOR COARSE-GRAINED SOILS

PART I: INTRODUCTION

Background

1. The mission of the Mobility and Environmental Division of the U. S. Army Engineer Waterways Experiment Station (WES) is to conduct research that will lead to an improvement in the overall mobility of ground-contact military vehicles. Before marked improvement in mobility can be effected, an understanding of the fundamental relations of terrain-vehicle systems must be developed. One phase of the research is the development of mathematical expressions that (a) include all pertinent independent tire and soil parameters and (b) can be used to predict the performance of soils under moving tire loads.

2. The details of the test program "Performance of Soils Under Tire Loads" and the essential test equipment and techniques thereof are described in Report 1 of this series, and subsequent reports in the series contain first-order analysis of various portions of the test data.[1] Basic data from previous tests of this program and data from other WES field test programs[2] are the principal sources of the data presented herein.

Purpose of This Study

3. The purpose of this study was to develop relations between the performance coefficients and independent tire-soil and system parameters that would (a) be useful to the designer in selection of the number and size of tires required to achieve a desired degree of mobility and (b) permit prediction of the soft-soil performance of pneumatic-tired vehicles.

Scope

4. This study was limited to tests with single wheels and a

four-wheel-drive test vehicle on one air-dry sand in the laboratory, and a review of selected data from tests with nine different pneumatic-tired vehicles on dry-to-moist undisturbed beach and dune sands. Each single-wheel test usually consisted of a series of five consecutive passes of a test tire in the same path. During these laboratory tests, soil strength, wheel load, tire geometry, and tire deflection were varied. The tires selected for the tests, designated basic test tires in this report, provided a systematic variation in tire diameter and section width, and permitted an evaluation of (a) model-prototype relations and (b) the effects of tire width and diameter on performance. Tire loads and inflation pressures were varied to produce hard-surface deflections of 15, 25, and 35 percent. During the tests with the basic test tires, sand consistency varied from 0.7 to 8.3 $N/cm^2/cm$* penetration resistance gradient (density approximately 1.44 to 1.65 g/cm^3; 0- to 15-cm cone index approximately 7 to 90 psi). In the field data selected for this analysis, tire load, tire geometry, tire deflection, and soil strength were variable quantities.

Special Definitions

5. Certain terms that facilitate analysis of data and communication of test results are rigorously defined in Report 1 of this series. Only those additional terms that are considered essential to this report are defined below.

Depth of influence: The depth range (e.g. 0 to 15 cm) for which changes in density of the soil noticeably affect the performance of pneumatic tires. In this text, the depth of influence is assumed to be equal to the section width of the tire.

Dynamic load transfer: The transfer of load from one axle to another resulting from differential rutting, slope of surface, or application of torque to the wheels.

Dynamic radius (r_e): The undeflected radius minus the dynamic in-soil deflection measured directly beneath the axle.

* A table of factors for converting metric units of measurement to British units is presented on page vii.

Internal rolling resistance: The force required to tow a given vehicle in neutral gear on an unyielding surface.

Penetration-resistance gradient (G): The slope of the curve of penetration resistance versus depth averaged, in this analysis, for a depth equal to the width of the tire.

Spissitude (β): Change in a soil's resistance to penetration as a result of the rate of deformation. The meaning of this word is somewhat similar to that of viscosity, but it is utilized to avoid misuse of the rather specific technical meaning of viscosity.

Towing force (maximum drawbar pull): The maximum sustained towing force a self-propelled vehicle can produce at its drawbar under given test conditions. (Note: Towing force-load ratio approximates maximum slope negotiable.)

PART II: SOIL PREPARATION AND TEST EQUIPMENT

Soil Preparation

6. The sand used in the laboratory tests was taken from an active dune near Yuma, Arizona. Fig. 1 shows the gradation and classification of this soil, which was classified as SP-SM in accordance with the Unified Soil Classification System. The field tests were conducted on undisturbed sands in the desert near Yuma, Arizona, and on various beaches in the United States and abroad.

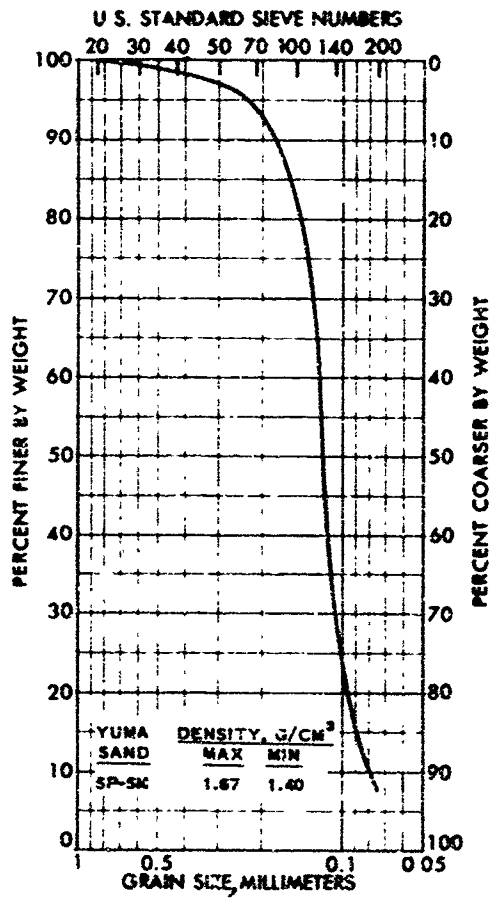

Fig. 1. Gradation and classification of Yuma sand

Laboratory tests

7. In the laboratory tests the sand was placed in the soil bins shown in fig. 2. Five bins were joined end to end to provide a test course long enough for the test carriage to be accelerated to the desired speed, a programmed-slip test to be conducted, and the carriage to be decelerated. The actual test lane was two bins, or 16.5 m, long. The soil in these two bins was harrowed to a depth of 43 cm, and the surface was compacted with a pneumatic-tired roller and leveled before each test. The objective of the soil processing was to prepare uniform test sections in which the increase in strength with depth was approximately linear to a depth at least as great as the width of the test tire. This objective was achieved generally, but there were exceptions. Typical profiles, representing two different strength levels, are shown in fig. 3.

Fig. 2. Soil bins

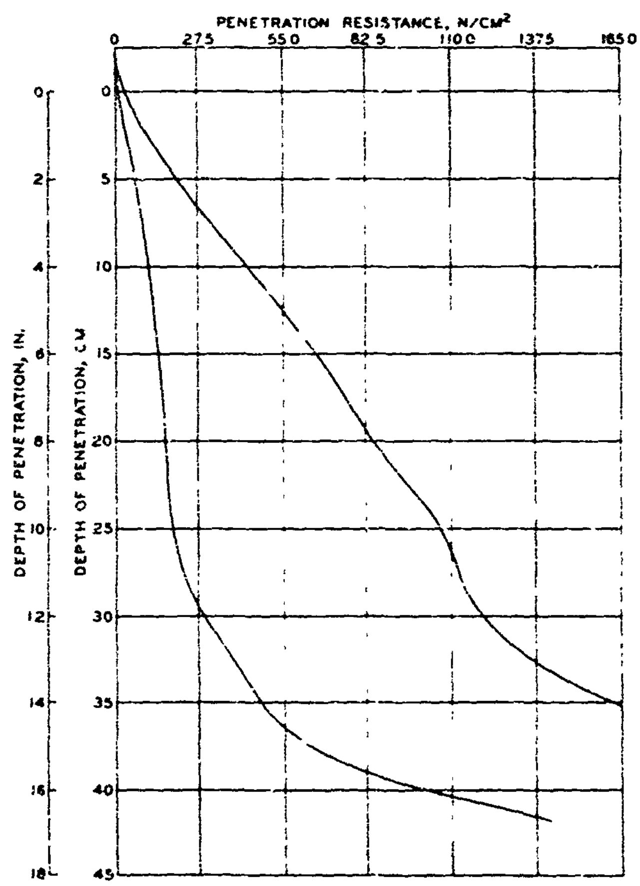

Fig. 3. Typical profiles of Yuma sand

Field tests

8. Surface slope and soil strength were measured on the unprepared (natural) test areas, otherwise the areas were not disturbed prior to tests.

Test Equipment

Test tires

9. Basic test tires. For the test program, a basic set of test tires was selected to provide a systematic variation in the principal tire dimensions--diameter and section width. These tires are shown in fig. 4,

Fig. 4. Basic test tires

and their dimensions are as follows.

Nominal Size	Diameter cm	Section Width, cm	Section Height, cm
4.00-7	35.8	10.7	7.9
4.00-20	71.2	10.7	8.1
6.00-16	72.2	16.8	13.5
9.00-14	72.2	21.1	16.3

The dimensions listed are average values, as the actual size varied slightly with inflation pressure (table 1). The exterior dimensions of the 9.00-14 tire are approximately twice those of the 4.00-7. The diameter of the 4.00-20 tire is almost the same as that of the 9.00-14, but is twice that of the 4.00-7. The section width of the 4.00-20 tire is about half that of the 9.00-14 tire and the same as that of the 4.00-7 tire. The diameter of the 6.00-16 tire is the same as that of the 9.00-14 and approximately the same as that of the 4.00-20, but the section width is of intermediate dimension.

10. These tires were of flexible, two-ply construction with nearly circular cross sections and were buffed free of tread. They were mounted on steel rims with standard flanges and tested without tubes. Detailed tire data are listed in table 1.

11. Validation test tires. Four tires, of dimensions different from those of the basic test tires, were used to validate the performance relations developed from tests with the basic test tires. The validation test tires were selected because they represented a wider range of sizes and shapes than did the basic tires. Furthermore, in some of the tests conducted with these tires, the penetration resistance-depth curves were different from those associated with tests of the basic tires in that the strength usually increased uniformly with depth to a depth of only 15 cm. At greater depth, the rate of increase varied, but was generally less than that of the first 15 cm. The validation test tires are shown in fig. 5, and their dimensions are as follows.

Nominal Size	Diameter cm	Section Width cm	Section Height cm
16x15-6R (Terra tire)	43.2	38.6	13.2
11.00-20	104.8	29.0	22.8
1.75-26 (bicycle tire)	71.6	4.3	3.6
9.00-14	69.1	21.8	14.7

The 11.00-20, 12-PR standard military tire has essentially conventional proportions, and was tested with a tube.*

* This tire was tested on a large, single-wheel dynamometer carriage considered to be mechanically equivalent to the one described in paragraph 12.

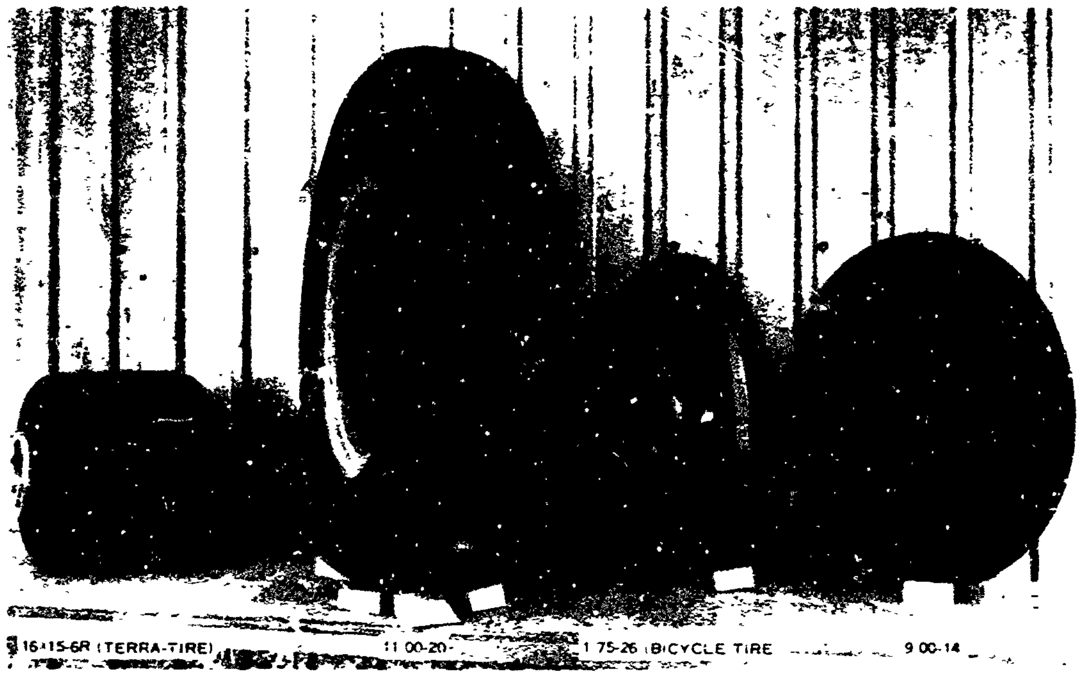

Fig. 5. Validation test tires

The 1.75-26 tire is a common commercial bicycle tire and also requires a tube. Its diameter is about 16 times its width. The 16x15-6R Terra tire is tubeless and its width almost equals its diameter. The 9.00-14, 2-PR tire was of the same general size and shape as the basic test tire of the same size. Validation test tire data are given in detail in table 2.

Test carriage

12. The single-wheel dynamometer test carriage (fig. 6) is instrumented to provide a continuous record of pull, torque, wheel sinkage, wheel load, velocity, and slip. A detailed description of the carriage is given in Report 1 of this series.

Test vehicles

13. The vehicle performance data selected include data from tests with conventional pneumatic-tired vehicles used in the field and a modified four-wheel-drive vehicle used in the laboratory. Pertinent vehicle and tire data for the field tests have been extracted from Supplement 17 of Technical Memorandum No. 3-240.[2] Tire dimensions of the field test vehicles are as follows:

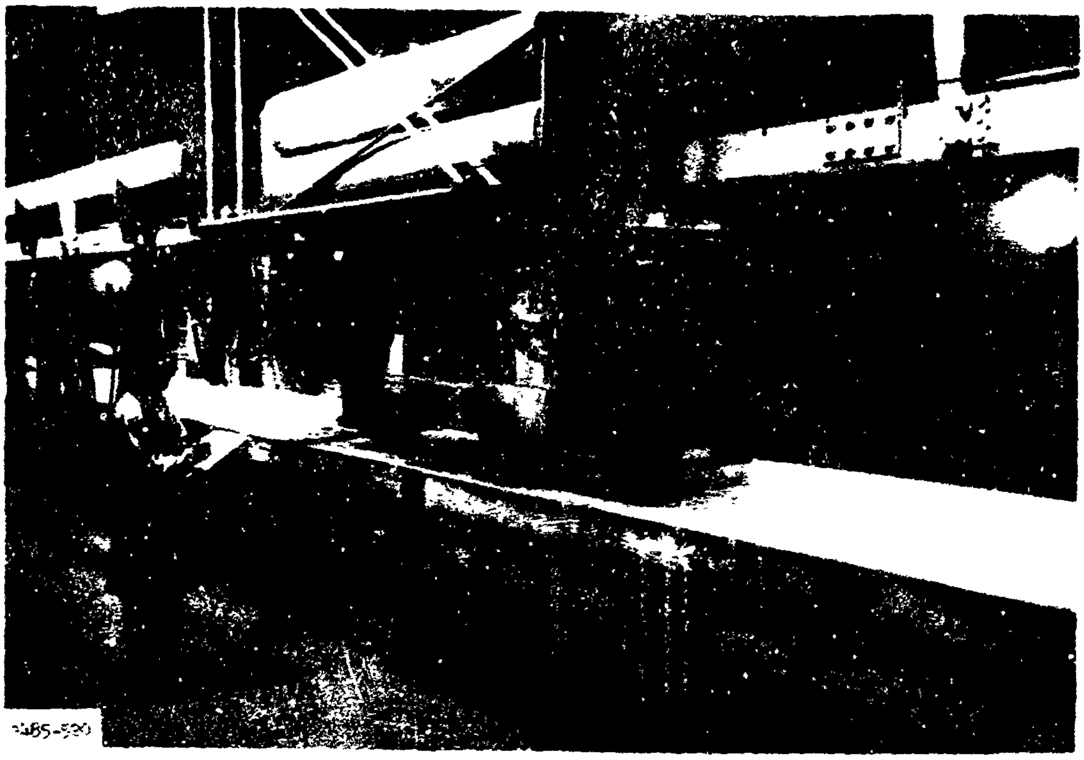

Fig. 6. Test carriage in position on soil cars

Vehicle	Nominal Tire Size	Diam, d cm	Section Width, b cm	Section Height, h cm
M38A1, 4x4 Jeep, 1/4-ton*	7.00-16	76.2	18.42	15.88
M37, 4x4 truck, 3/4-ton	9.00-16	86.4	23.37	21.21
M34 and M135, 6x6 truck, 2-1/2-ton	11.00-20	104.9	28.70	24.13
M41, 6x6 truck, 5-ton	14.00-20	124.5	36.83	30.48
DUKW 353, 6x6 truck, 2-1/2-ton (Amphibian)	14.00-20	124.5	36.83	30.48
Bucket loader, 4x4 tractor	14.00-24	134.6	36.07	30.48
Tournadozer, 4x4 tractor	21.00-25	166.4	55.63	45.72
XM520 GOER, 4x4 cargo carrier, 5-ton	18.00-26	160.0	46.99	40.13
XM520 GOER, 4x4 cargo carrier, 5-ton	15.00-34	165.6	45.97	36.83

* Multiply by 0.907185 to get metric tons.

PART III: DIMENSIONAL FRAMEWORK

14. In a brief analysis of the bearing capacity of soft soils under tracked vehicles, Markwick[3] introduced dimensional analysis as a means of studying soil-vehicle systems. Other experimenters have used similar techniques as an aid to vehicle mobility research. Their work is described in references 4-15. Several of the references contain a development of the Pi terms related to the soil-vehicle system. Therefore, this report only contains tabulations of the pertinent tire-soil parameters and the Pi terms used to develop functional equations.

Independent Parameters

15. The independent parameters of a soil-vehicle system were divided into three groups: soil parameters, tire parameters, and system parameters.

Parameter	Symbol	Mass, Length, Time (MLT) Units
Soil:		
Friction angle	ϕ	--
Cohesion	c	$ML^{-1}T^{-2}$
Density	γ	$ML^{-2}T^{-2}$
Spissitude	β	$ML^{-1}T^{-1}$
Tire:		
Diameter	d	L
Section width	b	L
Section height	h	L
Deflection	δ	L
System:		
Load	W	MLT^{-2}

(Continued)

Parameter	Symbol	Mass, Length, Time (MLT) Units
System (Cont'd):		
Translational velocity	V	LT^{-1}
Slip	S	--
Tire-soil friction	f	--
Acceleration of gravity	g	LT^{-2}

Dependent Parameters

16. The dependent parameters of the system in this study were the major performance characteristics:

Parameter	Symbol	MLT Units
Pull	P	MLT^{-2}
Towed force	P_T	MLT^{-2}
Torque	Q	ML^2T^{-2}
Sinkage	z	L

Pi Terms (General Functional Equations)

17. The independent and dependent parameters listed in paragraphs 15 and 16 were combined, using the diameter d as a characteristic tire dimension, to generate the following Pi terms:

Term	Descriptive Title
$\frac{P}{W}$	Pull coefficient
$\frac{z}{d}$	Sinkage coefficient
$\frac{Q}{dW}$	Torque coefficient
$\frac{P_T}{W}$	Towed coefficient

(Continued)

Term	Descriptive Title
$\frac{cd^2}{W}$	Clay loading number
$\frac{\gamma d^3}{W}$	Sand loading number
$\frac{b}{d}$	Shape number
$\frac{\delta}{h}$	Deflection number
$\frac{h}{d}$	Height-diameter ratio
$\frac{V^2}{gd}$	Froude number
$\frac{W}{\beta dV}$	Velocity number
ϕ	Angle of internal friction
s	Wheel slip
f	Tire-soil friction

General Functional Equations

18. The Pi terms enumerated in the preceding paragraph can be combined to produce the following general equations, which are similar in form to those presented by other authors.[8,15]

For the pull coefficient:

$$\frac{P}{W} = f'\left(\frac{\delta}{h}, \frac{b}{d}, \frac{h}{d}, \phi, \frac{cd^2}{W}, \frac{\gamma d^3}{W}, \frac{V^2}{gd}, \frac{W}{\beta dV}, s, f\right)$$

For the sinkage coefficient:

$$\frac{z}{d} = f''\left(\frac{\delta}{h}, \frac{b}{d}, \frac{h}{d}, \phi, \frac{cd^2}{W}, \frac{\gamma d^3}{W}, \frac{V^2}{gd}, \frac{W}{\beta dV}, s, f\right)$$

For the torque coefficient:

$$\frac{Q}{dW} = f'''\left(\frac{\delta}{h}, \frac{b}{d}, \frac{h}{d}, \phi, \frac{cd^2}{W}, \frac{\gamma d^3}{W}, \frac{V^2}{gd}, \frac{W}{\beta dV}, s, f\right)$$

For the towed coefficient:

$$\frac{P_T}{W} = f''''\left(\frac{\delta}{h}, \frac{b}{d}, \frac{h}{d}, \phi, \frac{cd^2}{W}, \frac{\gamma d^3}{W}, \frac{V^2}{gd}, \frac{W}{\beta dV}, s, f\right)$$

Simplification of Functional Equations

19. By control of the test conditions and the use of certain substitutions in the basic Pi terms, the preceding equations can be simplified to manageable proportions, and the more important relations between the variables of the tire-soil system can be evaluated systematically.

Soil parameters

20. A soil that is almost purely frictional was selected; thereby the clay loading number $\frac{cd^2}{W}$ was eliminated. Penetration-resistance studies conducted prior to this test program indicated that the effect of velocity on the penetration resistance of this air-dry sand was negligible; therefore, the velocity number $\frac{W}{\beta dV}$ was omitted in the simplified analysis.

21. Several experimenters have shown that the friction angle ϕ of a cohesionless, dry sand is proportional to the density γ .[16,17] Therefore, ϕ was not included as a separate parameter. It has been determined also that the penetration-resistance gradient G is related to the density of a frictional soil. Since the penetration resistance is a very sensitive indicator of density change and since in-situ density measurements are difficult to obtain in loose air-dry sand, the penetration-resistance gradient G was substituted for γ . Both terms are expressed in similar units, $ML^{-2}T^{-2}$. It should be noted that in dry, cohesionless sand, the penetration resistance at the surface will be small and will not greatly affect the value of the gradient.

Tire parameters

22. Four tire geometry parameters-- b , d , δ , and h --were considered in this analysis. The three Pi terms chosen to represent these parameters were $\frac{b}{d}$, $\frac{h}{d}$, and $\frac{\delta}{h}$. The basic test tires are roughly toroidal in shape; hence, the ratio of section height to section width is very

nearly constant for the group. This permitted the number of Pi terms to be reduced to two, $\frac{b}{d}$ and $\frac{\delta}{h}$. The tire diameter d was chosen as the characteristic tire dimension in the first phases of the analysis. Later, detailed examination of the data allowed the other tire dimensions to be incorporated in the loading numeric.

System parameters

23. The four performance coefficients, the tire-to-soil friction coefficient, the Froude number, and the slip value are considered system parameters. Since it was not considered practical to study the effect of slip as an independent variable, the pull, torque, and sinkage coefficients were evaluated at a constant slip value. The slip value chosen was 20 percent. There are several reasons for this choice. The maximum pull developed during laboratory tests generally occurred near 20 percent slip. Also, it was observed that soil-to-soil failures, as evidenced by the formation of visible shear planes (fig. 7), occurred during the tests as the slip value approached 20 percent; similar observations were made during the field tests. The fact that soil-to-soil failures were observed justifies the deletion of the tire-soil friction term f. The effect of speed on performance was assumed to be negligible; therefore, the Froude number $\frac{V^2}{gd}$ was deleted from the general functional equations.

Fig. 7. Shear displacements in tire path

24. The range of slip values associated with the towed coefficient was quite large, but the slip in this case can be considered a dependent variable and was not included in the simplified functional equation for the towed coefficient.

Refinements

25. Torque coefficient. The torque coefficient $\frac{Q}{dW}$ can be made more explicit by replacing the diameter d with the dynamic radius r_e to obtain the form $\frac{Q}{r_e W}$. Since the dynamic radius more closely

approximates the moment arm of the soil forces that provide the resistance to the applied torque Q, the magnitude of the torque coefficient in this form is more nearly equal to the sum of the pull and towed coefficients. (If the tire is on a plane surface that is parallel to the travel direction, and if the towed force P_T is equal to the motion resistance at 20 percent slip, then $\frac{Q}{r_e W} = \frac{P_{20}}{W} + \frac{P_T}{W}$.)

26. Tire deflection (laboratory data). In these tests, the wheel was loaded pneumatically,[1] and the applied load was continuously recorded. In some instances, the pneumatic loading system was unable to provide a constant load during a specific test. Since the inflation pressure remained relatively constant, the deflection of the tire was affected by these changes in load. This suggested that the data used in the dimensionless numbers should be those corresponding to the conditions actually imposed on the wheel at the time the performance was measured. To effect the needed adjustments, a series of plots similar to the one shown in fig. 8 were utilized. For example, if the planned load W and deflection number $\frac{\delta}{h}$ were 1000 N and 15 percent, but the load dropped to 955 N during the test, the corresponding deflection would be 14.5 percent (fig. 8). The values of the sand loading number $\frac{Gd^3}{W}$, the sand number $\frac{G(bd)^{3/2}}{W}$, and the sand mobility number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$ subsequently discussed in this report all employ the load actually measured at the data station and the hard-surface deflection that corresponds to that load and inflation pressure. This adjustment reduced scatter in plots of performance data so that relations between the independent and dependent

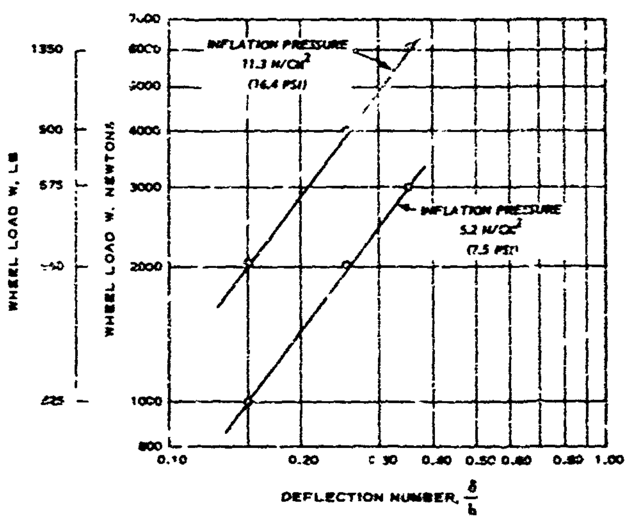

Fig. 8. Deflection number versus wheel load

parameters could be delineated with greater assurance.

27. Tire deflection (field data). Because of the conditions prevailing in the field, deflection data were not obtained for every combination of load and inflation pressure tested. Therefore, it was necessary to estimate the test tire deflection from a plot such as that shown in fig. 8 using the load and inflation pressure recorded for each test.

Pi Terms (Simplified Functional Equations)

28. From consideration of the restrictions and simplifications discussed in the preceding paragraphs, Pi terms used in the analysis are as follows:

Term	Descriptive Title
$\frac{P}{W}$	Pull coefficient
$\frac{z}{d}$	Sinkage coefficient
$\frac{Q}{r_e W}$	Torque coefficient
$\frac{P_T}{W}$	Towed coefficient
$\frac{Gd^3}{W}$	Sand loading number
$\frac{b}{d}$	Shape number
$\frac{\delta}{h}$	Deflection number

29. The simplified functional equations become:

$$\frac{P}{W} = f'\left(\frac{Gd^3}{W}, \frac{b}{d}, \frac{\delta}{h}\right)$$

$$\frac{z}{d} = f''\left(\frac{Gd^3}{W}, \frac{b}{d}, \frac{\delta}{h}\right)$$

$$\frac{Q}{r_e W} = f''' \left(\frac{Gd^3}{W} , \frac{b}{d} , \frac{\delta}{h} \right)$$

$$\frac{P_T}{W} = f'''' \left(\frac{Gd^3}{W} , \frac{b}{d} , \frac{\delta}{h} \right)$$

PART IV: TEST RESULTS

Analysis

30. The purpose of this analysis was to determine systematically the effect that changes in soil strength, wheel load, and tire geometry, including deflection, have on performance.

Effect of soil strength

31. The simplified functional equations contain only one term, $\frac{Gd^3}{W}$, that includes soil strength. As stated in paragraph 7, the test sections were constructed so that the slope of the penetration resistance versus depth relation was relatively constant. However, for the evaluation of the laboratory and field tests with abnormal profiles, it was necessary to devise a method to account for the effect of the deviations from a linear strength-depth relation. Existing soil mechanics theories indicate that the depth range for which changes in density or soil strength affect the bearing capacity of sand is proportional to the width of the footing--in this case, the tire. On the other hand, the resistance to the torque of a powered wheel is developed by displacements perpendicular to the width direction. Thus, the theories provide only general guidance. Examination of some of the early test data suggested that the results of tests on markedly dissimilar strength-depth profiles could be grouped by simply averaging the penetration-resistance data for a depth range equal to the width of the tire.

32. As a check, tests were conducted in specially prepared test sections in which abrupt changes in soil strength occurred at various depths. Plate 1 shows penetration-resistance curves for a series of such test sections. The rate of increase in strength with depth in both the upper and lower soil layers was nearly constant for this series of tests. Performance data for an 11.00-20 tire in these test sections are tabulated on the following page.

33. These data indicate that changes in the strength of the soil below a depth of approximately 24 cm, which equals 0.83b in this case, did not noticeably affect the level of performance (plate 2). It is recognized

Test No.	Deflection %	Depth to Discontinuity, cm	Wheel Sinkage cm	Torque m-N	Pull N	Wheel Load, N	Pull Coefficient P/W
79	15	9.50	3.66	2463	2088	13,622	0.153
83	15	16.00	4.80	2293	1155	13,524	0.085
85	15	17.80	6.58	2399	911	13,622	0.067
87	15	20.60	6.98	2541	822	13,755	0.060
89	15	23.60	8.48	2660	711	13,724	0.052
91	15	27.20	8.84	2788	720	13,710	0.052
81	15	29.85	8.38	2717	711	13,773	0.052
93	15	34.30	9.07	2893	729	13,555	0.054
80	35	9.50	2.34	3247	5644	14,502	0.389
84	35	16.00	2.41	2908	4489	13,755	0.327
86	35	17.80	2.69	2755	4000	13,853	0.289
88	35	20.60	2.64	2788	3733	13,866	0.269
90	35	23.60	3.17	2752	3644	13,778	0.264
92	35	27.20	3.48	2752	3555	13,600	0.262
82	35	29.85	3.63	2766	3422	13,355	0.256
94	35	34.30	3.91	2823	3511	13,600	0.258

that the depth of influence also will be affected by the relative soil strength of the layers. Since the slopes of the penetration-resistance curves in the upper layer for the specially prepared test sections (plate 1) were approximately equal to the median slope for the tests conducted with the basic test tires, it was assumed that the proposed procedure would yield a reasonable median for the basic tests. The test data also suggest that tire deflection was not a major influence on the depth over which the soil strength affects test results. For analysis of subsequent tests, then, the penetration-resistance gradient G was averaged for a depth range equal to the tire width.

34. The reliability of G as a measure of the relative consistency of the soil is demonstrated by data obtained from tests in which tire geometry remained constant. Plates 3, 4, and 5 contain plots of the

dependent performance coefficients $\frac{P}{W}$, $\frac{z}{d}$, $\frac{Q}{r_e W}$, and $\frac{P_T}{W}$ versus the sand loading number $\frac{Gd^3}{W}$. These data were obtained from a series of tests with the 9.00-14, 2-PR tire operating at deflections of 15, 25, and 35 percent. The maximum planned wheel load was 3950 N and the minimum, 1000 N. The soil gradient G ranged from 0.7 to 6.6 N/cm^2/cm. Some data scatter is evident, but there is no tendency for the data to separate by load. On each plot, a single smooth curve was used to delineate the relation between the independent variables and the sand loading number $\frac{Gd^3}{W}$. It was concluded from these data that the soil parameter G was a satisfactory indication of the relative strength or density of this soil.

35. The curves that describe the relations of pull, sinkage, and towed coefficient to the sand loading number are generally hyperbolic in shape. The largest values of the pull coefficient are associated with the largest values of the sand loading number. Conversely, the largest values of sinkage and towed coefficients are associated with relatively small values of the sand loading number. The torque coefficient increases slightly as the sand loading number increases.

Effect of load

36. In the preceding paragraphs, the effect of load variations on performance was not discussed. The effect of changes in load can be examined by comparing groups of tests using a single tire size at a constant deflection number. Plate 6a presents data obtained from tests with a 9.00-14, 2-PR tire at 15 percent deflection and is a plot of the pull coefficient versus the soil strength parameter G . A separate curve is required to represent the test data for each load. When the same pull coefficient data are plotted versus G/W (plate 6b), a single curve can be used to represent all loads (d is constant). This indicates that the effect of load was adequately considered in the sand loading number.

Effect of tire geometry

37. Evaluation of model-prototype relations. Results of tests conducted with the 4.00-7 (model) and the 9.00-14 (prototype) tires were used to determine whether the tire performance data followed a true model-prototype relation. The pull, sinkage, towed, and torque coefficients were used to compare the similarity in the geometry of the two systems. Plate 7

contains the data for tests conducted at 35 percent deflection. Tests at 15 and 25 percent deflection showed similar results. The data are intermingled on each plot, indicating geometric and dynamic similarity between model and prototype. This comparison also corroborates the assumption that velocity effects were negligible for the speed range represented since both size tires were operated at the same forward (linear) velocity during these tests, rather than at scaled velocities. In addition, these data also support the use of the soil strength parameter G . The slopes of the penetration-resistance curves were averaged over a depth approximately equal to the width of the test tire used. Since the slopes of the penetration-resistance curves were not constant in each case, the intermingling of test data seems to indicate that the effect of the soil properties was adequately reflected in the soil strength parameter.

38. Effect of tire width. To determine the effect of tire width on performance, tests were conducted with three tires of nearly equal diameter but of different widths. These were the 9.00-14, 6.00-16, and 4.00-20 tires; their shape numbers (b/d) were 0.291, 0.233, and 0.150, respectively. The first step in analyzing the effect of width was to determine the relation of the four performance coefficients to the sand loading number. Data for tests conducted at 15, 25, and 35 percent deflection are given in tables 3 and 4. Similar relations were found at all three deflections. Results of tests at 35 percent deflection shown in plate 8 are typical. Families of curves delineate the relations of the four performance coefficients to the loading number, with a separate curve on the plot representing the data for tests with each tire.

39. The second step was to construct cross plots to relate the shape number to the loading numbers at several levels of performance for each deflection number. Plate 9 shows cross plots of data from the relations of pull coefficient and sinkage coefficient to the sand loading number for the three deflections. From these logarithmic plots, the relation of the reciprocal of the shape number to the sand loading number can be expressed as follows:

$$\frac{d}{b} = K\left(\frac{Gd^3}{W}\right)^{2/3} = \frac{KG^{2/3}d^2}{W^{2/3}}$$

where K is a constant of proportionality. Raising both sides to the 3/2 power:

$$\frac{d^{3/2}}{b^{3/2}} = K^{3/2}\,\frac{G}{W}d^3$$

$$\frac{G}{W}(bd)^{3/2} = \frac{1}{K^{3/2}} = \text{constant}$$

40. This leads to the conclusion that for each constant value of a performance coefficient for a given deflection number, there is a corresponding value composed of the pertinent independent variables, including the shape number. This combination, $\frac{G(bd)^{3/2}}{W}$, is designated the sand number. To illustrate the data collapse achieved with this number, the performance coefficients were plotted versus the loading number from tests at 15, 25, and 35 percent deflection. Results of the tests at 15 percent deflection shown in plate 10 are representative. Note that the data do not separate on the basis of tire size. The relation of each of the four performance coefficients to the loading number is well defined. However, in an earlier analysis of these data,[15] the relation of the torque coefficient to the sand number was not well defined. The improved definition is believed to be due to the increased range of data available for analysis and the correction of the deflection number to account for changes in load during the tests (see paragraph 26).

41. Effect of tire diameter. The sand number should adequately account for the effect of tire diameter on the magnitude of the performance coefficients. Data obtained from tests with the 4.00-20 (71.2-cm diameter) and 4.00-7 (35.8-cm diameter) tires were used to evaluate this hypothesis. Plate 11 contains data from tests conducted at 25 percent deflection. Similar results were obtained from tests conducted at 15 and 35 percent deflection. Some scatter is evident (this appears to be large

because of the scale used for the sand number), but the intermingling of the plotted points representing the two tires demonstrates that the sand number adequately accounts for the effects of tire diameter.

42. Effect of tire deflection. In the analysis of the effects of soil strength, tire width, and tire diameter on the wheel's performance, it was readily apparent that tire deflection significantly affected the level of performance. Plates 12 and 13 present the relation of the pull and sinkage coefficients, respectively, to the sand number. Smooth curves, representing constant values of the deflection ratio, are used in both plates to delineate the relations of the performance coefficients to the sand number. Note that the curves are of similar shape, but the values of the performance coefficients are obviously a function of tire deflection as well as of the factors included in the sand number.

43. The effects of deflection were determined from cross plots of the coordinates of points on the faired curves in plates 12 and 13. The reciprocal of the deflection number was plotted versus the values of the sand number for several constant values of the pull and sinkage coefficients. The relations that appear in plate 14 can be described adequately by a family of straight lines through the origin. The general mathematical expression for this family of straight lines is

$$\frac{h}{\delta} = K \times \frac{G(bd)^{3/2}}{W}$$

or

$$\frac{1}{K} = \frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$$

where K is the constant associated with a given value of a performance coefficient. This expression, which combines all of the independent Pi terms in the simplified functional equations (see paragraph 22), is termed the sand mobility number. Plate 15 shows the relation of the pull, sinkage, torque, and towed coefficients to the sand mobility number. The data points are shown to indicate the range of scatter. Symbols show the different deflections corresponding to each test. Some scatter is evident but no separation by deflection numbers is noticeable. Thus, the validity

of the sand mobility number has been established for a range of the deflection number (roughly 0.1 to 0.4). The form of the relation is such that as the deflection number approaches zero, the sand mobility number approaches zero also, which, in turn, implies very poor performance. A low deflection alone does not necessarily result in poor performance. Therefore, the quality of the relation must diminish at the very low values of the deflection number.

Evaluation of the Sand Mobility Number

44. Laboratory data obtained prior to this study offered an opportunity to evaluate the adequacy of the sand mobility number when tires having shapes different from those in the basic group were considered and when the rate of increase in the strength of the soil with depth was decidedly nonuniform. The laboratory data also permitted an evaluation of the relation of the sand mobility number to the performance coefficients for multiple passes in the same tire path. The available field data, although not directly comparable in many cases, illustrated the applicability of the sand mobility number to analysis of the performance of actual vehicles in natural soil.

Validation of single-wheel tests

45. Selected single-wheel performance data from tests previously conducted (table 5) were compared with the performance predicted from the relations developed in this analysis. Plate 16 compares the data obtained from tests with an 11.00-20, a 9.00-14, a 16x15-6R (Terra), and a 1.75-26 (bicycle) tire with the idealized performance curves. The bicycle and Terra tire data were included to illustrate that the performance coefficients of these tires with extremely different shape numbers conform to the same relation developed for the more conventional tires. The 11.00-20 data were included to increase the range of tire diameters studied. The 9.00-14 data were considered because the soil strength profiles associated with these tests were quite different from those for the basic group of tests with that tire. Representative soil strength profiles for tests

with the 9.00-14 basic and validation test tires and the 11.00-20 and Terra tires are shown in plate 17.

46. Although considerable scatter is apparent in plate 16, the idealized curves form a reasonable average of the validation data group. On the whole, these data support the performance relations developed. The scatter in the sinkage data (plate 16b) can be attributed in part to difficulties experienced in obtaining reliable sinkage measurements.

Relation to vehicle performance

47. Multiple-pass performance of single wheel. On most pneumatic-tired vehicles, two or more wheels travel in the same path. The performance of each wheel is influenced by the soil condition created by the preceding wheel or wheels. The result is considered to be similar to the performance of a single wheel on each of multiple passes in a single path. Plate 18 and tables 6 and 7 contain performance data for the single wheel for the second and third passes in the same path. The pull and torque coefficients developed during the second and third passes are lower than first pass values when compared at equal values of the mobility number. In plate 19, average curves representing the pull data for the first three passes of the wheel are summarized to emphasize the effects of repetitive traffic. The soil strength measured before traffic (tables 3, 4, 6, and 7) was used in computing the values of the sand mobility number, and this could contribute significantly to the scatter of the data points in plate 18 because the soil strength may increase or decrease under the action of the traffic, depending on the initial soil strength, the wheel load, tire size, etc.

48. Plate 20 shows the relation of the pull coefficient to the sand mobility number for the second and third pass performance when the soil strength values measured just prior to each pass were used to compute the mobility number (tables 8 and 9). The use of the "during traffic" soil strength values reduced the scatter somewhat for each pass, but the curves used to delineate the relations are not substantially different from those based on the "before traffic" strength data (plate 18). First, second, and third pass pull coefficient curves are compared in plate 21, and it can be seen that performance generally decreases with traffic. Soil strength

values measured before each pass were used to compute the sand mobility number. The second and third pass torque coefficient curves were also generally lower than those developed on the first pass (tables 3, 6, and 7). The reason for separation of the pull coefficient first- and third-pass curves at the higher values of the mobility number is not known; however, the associated torque coefficient curves also separated.

49. Vehicle tests (laboratory). The next step in establishing the utility of the sand mobility number was to evaluate the performance of an actual vehicle operating under controlled conditions in the laboratory. The test sections were prepared in the same manner as those for the single-wheel tests. The four-wheel-drive (4x4) test vehicle was modified so that all wheels would rotate at the same speed, and the spring suspension system was replaced with rigid connections. These revisions, while not practical in everyday use, ensured that all wheels would operate at the same slip and that the wheel loads would not be influenced by dynamic oscillations. If the single-wheel apparatus and the test vehicle operate at the same degree of efficiency, the pull versus sand mobility number relation coefficient developed by the four-wheel-drive vehicle (table 10) should be the same as the average of the pull coefficient relations for the first and second passes of a single wheel. In plate 22, the results of the vehicle tests are shown as discrete data points, while the smooth curve represents the average of the first and second pass curves for the single wheel. The average curve was obtained from plate 19 simply by averaging the pull coefficients from each curve at common values of the sand mobility number. This curve adequately represents the relation formed by the performance data for the vehicle.

50. Vehicle tests (field). Field tests have been conducted on coarse-grained soils in various parts of the world with a variety of military vehicles.[2] These test results (table 11) are not fully comparable to the laboratory tests because the sand at the test sites usually was moist or even wet, and the drawbar-pull tests usually were not run at a controlled slip. Instead, tests were run at several levels of pull, and only the data relevant to the maximum drawbar attained were recorded for each test in the reference. Therefore, certain assumptions were necessary

to effect a first-order evaluation of the mobility number. These are as follows:

a. The cohesive forces were negligible; i.e., the surface cone index readings were small in relation to subsequent readings.

b. An equivalent G can be computed from the 0- to 15-cm penetration-resistance data recorded in the reference. This implies the approximation that the rate of increase in strength with depth (G) was constant for a given field test to a depth equal to the width of the test tires used.

c. The vehicles were loaded so that each tire carried an equal share of the load.

51. Results of tests with 4x4 and 6x6 vehicles listed in table 3 of reference 2b are recorded in table 11 and plotted in plate 23. The intermingling of data points for tests with a variety of vehicles and with different tire sizes, tread patterns, and inflation pressures demonstrates that the sand mobility number and the assumptions listed in the preceding paragraph provide a valid basis for grouping vehicle performance data. A single curve has been drawn in plate 23 to delineate the average relation of the pull coefficient to the sand mobility number for all the vehicles.

Comparison of vehicle and single-wheel performance relations

52. In plate 24, the field performance data for the test vehicles are compared to the average of the first, second, and third pass performance curves obtained for single wheels in the laboratory. The single-wheel data were evaluated in terms of the soil strength data measured before traffic, since only the before-traffic strength data were available for the field tests. Both curves have the same general shape, but the ordinate values of the two curves differ by a nearly constant amount; i.e., the single-wheel data indicate a greater pull for a particular sand mobility number than was achieved during the vehicle tests. There are several factors that could contribute to the differences observed. These include differential wheel slip (front to rear and/or side to side), uneven wheel loading due to dynamic load transfer, and increased rolling resistance caused by imperfectly tracking rear wheels.

53. In plate 25, the relation of the towed coefficient to the sand

mobility number is compared to a similar relation developed for single wheels in the laboratory. These data for the field tests are listed in table 12. The difference in the ordinate values of the two curves at any value of the sand mobility number is equal to 2.5 percent of the wheel load or vehicle weight. Again, there are several factors that could contribute to these differences. These are internal friction and increased motion resistance due to imperfectly tracking rear wheels.

Performance Prediction

54. The relation of the single-wheel pull coefficient and the pull coefficient determined from vehicle tests to the sand mobility number (plate 25) offers the basis for a tentative performance prediction system and for design criteria for vehicles operating in dry-to-moist sands. Plate 26 contains curves representing the relations of the pull and towed coefficients for wheeled vehicles to the sand mobility number. These curves can be used to forecast the mobility of existing vehicles or to select tires that will provide the desired degree of sand mobility for existing or proposed vehicles. At the present time, it is suggested that the curves be used with caution because the research effort must be broadened to effect refinements of the strength parameters and the deflection parameters. It also must be extended to include larger tires and tires of unusual shape. The following examples are given to illustrate the possible practical use of the curves in predicting performance of specific vehicles. In each example, it has been assumed that each tire carries an equal share of the load. In addition, the assumption has been made that the tangent of a slope climbed is practically equivalent numerically to a pull coefficient. The basis for this assumption is given in reference 18. Field tests conducted since that time have generally verified this assumption.[2b] Usually for a given set of test conditions, the maximum pull coefficient is approximately 0.02 greater than the maximum slope negotiated. However, for this analysis, this slight difference has been ignored.

Example 1

55. Soil strength and wheel load are given; slope-climbing ability or maximum drawbar pull can be computed as in the calculations that follow.

Given: M135, 6x6 truck, 2-1/2-ton

Gross vehicle weight (nW) = 80kN

Number of wheels (n) = 6

Wheel load (W) = 13.3 kN

Soil strength (G) = 5.4 N/cm^2/cm

11.00-20 single tires: b = 28.7 cm; d = 104.9 cm; $(bd)^{3/2}$ = 165,000 cm^3; δ/h = 0.35

Find: Maximum drawbar-pull coefficient and slope negotiable.

Solution:

$$\Omega = \frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h} = \frac{5.4(165,000)(0.35)}{13.3 \times 1000}$$

$$\Omega = 23.5$$

Reading from plate 26, P/W = between 0.21 and 0.22; or from the equation for powered wheels in plate 26:

$$\frac{P}{W} = \frac{\Omega - 5.50}{2.12\,\Omega + 33.31}$$

$$\frac{P}{W} = \frac{23.5 - 5.5}{2.12(23.5) + 33.31}$$

$$\frac{P}{W} = 0.216$$

Conclusion: This vehicle, under the conditions specified, can climb a 21 percent slope; or on level ground, it can tow an object whose resistance does not exceed 21 percent of the weight of the prime mover. Finally, slope and maximum drawbar pull may be considered together; e.g., on a 10 percent slope, the vehicle can pull a trailer whose rolling resistance does not exceed 11.6 percent of the vehicle's weight.

Example 2

56. For design purposes, the equation can be manipulated to solve for tire size when the allowable deflection, the minimum soil strength, the design wheel load, and the required slope-climbing ability or drawbar pull are known. This is illustrated in the following calculations.

Given: Configuration = 6x6 vehicle, single-tandem tires

Gross vehicle weight (nW) = 125 kN

Number of wheels (n) = 6

Wheel load (W) = 21 kN

Soil strength (G) (minimum) = 5.4 N/cm^2/cm

Slope = 20 percent

Maximum allowable deflection (δ/h) = 0.35

Find: Tire sizes compatible with given conditions.

Solution:

$$\Omega = \frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$$

Solving for $(bd)^{3/2}$ yields:

$$(bd)^{3/2} = \Omega \times \frac{Wh}{G\delta}$$

and from the equation shown, the relation of the pull coefficient (equivalent to slope climbed) to the sand mobility number (plate 26),

$$\Omega = \frac{33.31\ P/W + 5.5}{1 - 2.12\ P/W}$$

Substituting the above for Ω :

$$(bd)^{3/2} = \frac{33.31\ P/W + 5.5}{1 - 2.12\ P/W} \times \frac{Wh}{G\delta}$$

$$(bd)^{3/2} = \frac{(33.31)(0.2) + 5.5}{1 - 2.12(0.2)} \times \frac{21 \times 1000}{(5.4)(0.35)}$$

$$(bd)^{3/2} = 234{,}600$$

$$bd = (234{,}600)^{2/3}$$

$$bd = 3804\ \text{cm}^2$$

Tire selection: Try 11.00-20, 12-PR nondirectional cross country; b = 28.7 cm; d = 104.9 cm; b × d = 3011 < 3804 (inadequate)

Try 14.00-20, 12-PR nondirectional cross country; b = 36.8 cm; d = 124.5 cm; b × d = 4585 > 3804 (adequate)

Try 46x18-20R, 8-PR Terra tire; b = 50 cm; d = 115 cm; b × d = 5750 > 3804 (adequate)

Conclusion: The 14.00-20 and the 46x18-20R tires are adequate. In the foregoing example, only two tires were demonstrated to be adequate. Obviously, there are many tires that fulfill the requirements from a mobility standpoint. The designer must select the tire that represents the best combination of stability, ground clearance, height of truck cargo bed, cost, etc.

Example 3

57. The mobility of a vehicle-trailer combination also may be estimated using the curves shown in plate 26. In this example, a minimum soil strength, a maximum slope, and the required vehicle and trailer data are known quantities. The necessary steps are given below.

Given: M37, 4x4 truck, 3/4-ton

Gross vehicle weight (nW) = 26.7 kN

Number of wheels (n) = 4

Wheel load (W) = 6.67 kN

Soil strength (G) (minimum) = 5.4 $N/cm^2/cm$

Slope (maximum) = 10 percent

9.00-16 tires: b = 23.4 cm; d = 86.4 cm; $(bd)^{3/2} = 90{,}730\ cm^3$; $\delta/h = 0.35$

M101, 2-wheel trailer

Gross vehicle weight (nW) = 8 kN

Number of wheels (n) = 2

Wheel load (W) = 4 kN

9.00-16 tires: b = 23.4 cm; d = 86.4 cm; $(bd)^{3/2} = 90{,}730\ cm^3$; $\delta/h = 0.35$

Find: Is the vehicle-trailer combination mobile under the conditions specified?

Solution: a. Vehicle pull:

$$\Omega = \frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h} = \frac{5.4(90,730)(0.35)}{6.67 \times 1000}$$

$$\Omega = 25.7$$

Reading from plate 26, P/W = 0.228; or from the equation for powered wheels in plate 26:

$$\frac{P}{W} = \frac{\Omega - 5.5}{2.12\ \Omega + 33.31}$$

$$\frac{P}{W} = \frac{25.7 - 5.5}{2.12(25.7) + 33.31}$$

$$\frac{P}{W} = 0.230$$

Maximum drawbar pull on level ground = $\frac{P}{W}$ (nW) = (0.230)(26.7) = 6.14 kN

b. Maximum drawbar pull of vehicle on 10 percent slope: Maximum drawbar pull on a 10 percent slope = $\frac{P}{W}$ (nW) - slope (nW)

= (0.230)(26.7) - (0.10)(26.7)

= 6.14 - 2.67

= 3.47 kN, or 3470 N

c. Trailer rolling resistance (level surface):

$$\Omega = \frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h} = \frac{5.4(90,730)(0.35)}{4 \times 1000}$$

$$\Omega = 42.9$$

Reading from plate 26, P_T/W = 0.077; or from the equation for towed wheels in plate 26:

$$\frac{P_T}{W} = \frac{0.00044\ \Omega + 0.0055}{0.01144\ \Omega - 0.0295} + 0.025$$

$$\frac{P_T}{W} = \frac{0.00044(42.9) + 0.0055}{0.01144(42.9) - 0.0295} + 0.025$$

$$\frac{P_T}{W} = 0.053 + 0.025 = 0.078$$

Rolling resistance on level ground (M101)

$$P_T = \frac{P_T}{W}(nW) = 0.078(8) = 0.624 \text{ kN, or } 624 \text{ N}$$

d. Rolling resistance on 10 percent slope:

Rolling resistance on a 10 percent slope

$$= \frac{P_T}{W}(nW) + \text{slope } (nW)$$

$$= 0.624 + (0.1)(8) = 1.42 \text{ kN}$$

e. Is maximum drawbar pull of an M37 on a 10 percent slope greater than the rolling resistance of an M101 trailer on a 10 percent slope under the conditions specified?

Maximum drawbar pull of an M37 on a 10 percent slope = 3.47 kN. Rolling resistance of M101 on a 10 percent slope = 1.42 kN. The M37's drawbar pull is greater.

Conclusion: Vehicle's drawbar pull exceeds the trailer's rolling resistance, so the vehicle-trailer combination will be mobile under the conditions specified. Carrying the calculations further, it can be seen that the combination would be immobilized on a slope of 15 to 16 percent, i.e., let

(slope) (M37 weight) + (slope) (M101 weight) + rolling resistance (M101) = maximum drawbar pull (M37)

$$(26.7)(\text{slope}) + (8)(\text{slope}) + 0.624 = 6.14$$

$$34.7(\text{slope}) = 5.52$$

$$\text{slope} = 0.16$$

Example 4

58. An all-wheel-drive vehicle has definite advantages over similar vehicles with nonpowered elements. The relations of pull and towed force to the sand mobility number can be used to show the advantages gained by

powering all the wheels. The M37, discussed in the previous example, can be used as a 4x4 or 4x2 vehicle, because the front axle can be engaged manually.

Given: M37, 4x4 truck, 3/4-ton

Gross vehicle weight $(nW) = 26.7$ kN

Number of wheels $(n) = 4$

Wheel load $(W) = 6.67$ kN

Soil strength (G) (minimum) $= 5.4$ N/cm^2/cm

9.00-16 tires: $b = 23.4$ cm; $d = 86.4$ cm; $(bd)^{3/2} = 90{,}730$ cm^3; $\delta/h = 0.35$

Find: Performance of M37: (a) as a 4x4 and (b) as a 4x2.

a. Pull coefficient and/or slope negotiable for 4x4 configuration:

From a of example 3: $\Omega = 25.7$; $P/W = 0.230$

b. Pull coefficient and/or slope negotiable for 4x2 configuration:

P/W = maximum drawbar pull of rear wheels minus rolling resistance of front wheels

(1) Maximum drawbar pull of rear wheels:

From a of example 3: $P/W = 0.230$

Total weight of rear axle = 13.3 kN

Maximum drawbar pull (0.230)(13.3) = 3.06 kN

(2) Rolling resistance of front wheels:

From the calculation of the sand mobility number given in example 3: $\Omega = 25.7$; and reading from plate 26, $P_T/W = 0.085$; or from the equation for towed wheels in plate 26:

$$\frac{P_T}{W} = \frac{0.00044\ \Omega + 0.0055}{0.01144\ \Omega - 0.0295} + 0.025$$

$$\frac{P_T}{W} = \frac{0.00044(25.7) + 0.0055}{0.01144(25.7) - 0.0295} + 0.025$$

$$\frac{P_T}{W} = 0.065 + 0.025 = 0.089$$

Total weight on front axle = 13.3 kN

Total rolling resistance on front wheels

(0.089)(13.3) = 1.18 kN

(3) Maximum drawbar pull (rear) (3.06 kN) - rolling resistance (1.18 kN) = 1.88 kN

$$\frac{P}{W} = \frac{1.88}{26.7} = 0.070$$

Conclusion: The 4x4 will outperform the 4x2. The latter would be immobilized on slopes of 7 percent or greater, while the 4x4 could negotiate slopes as steep as 23 percent.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

59. The foregoing analysis is considered adequate basis for the following conclusions:

a. The soil parameter G adequately defines the strength of soil for the range of conditions encountered in the laboratory tests. (Paragraph 34.)

b. The deflection parameter δ/h is adequate for the range of deflections considered. (Paragraph 43.)

c. The performance of pneumatic tires operating in sand, when speed and slip are constant, is dependent on the tire diameter, width, and deflection on load, and on soil strength. In dry sand, these factors can be combined into the dimensionless expression

$$\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h} .$$ (Paragraph 46.)

d. The average of the pull coefficients for the first and second pass of a single wheel forms a reasonable average of the points representing performance data for an actual 4x4 vehicle under laboratory conditions. (Paragraph 49.)

e. The expression $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$ adequately collapses the field performance data; i.e., the relation between the vehicle's field performance and the sand mobility number is similar to the relation for the laboratory performance data and the mobility number. (Paragraph 51.)

f. The relations found can be utilized for tentative design criteria or performance prediction. (Paragraphs 54-58.)

Recommendations

60. It is recommended that:

a. The study of effectiveness of the soil strength parameter be extended.

b. The range of tire deflection conditions tested be broadened and the possibility be investigated of altering the form of the sand mobility number so that the performance of rigid wheels can be considered.

c. Larger tires and tires of different basic shapes be included in this program.

d. The program be extended to other soils, including those that have both cohesive and frictional strength.

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Table 3

Characteristics of Basic Test Tires

Deflection %	Load N	Inflation Pressure N/cm² No Load	Inflation Pressure N/cm² Loaded	Carcass Section Height, cm No Load	Carcass Section Height, cm Loaded	Section Width, cm No Load	Section Width, cm Loaded	Tire Diam cm	Measured Rolling Circumference cm	Hard Surface Measurements: Contact Area cm²	Contact Length cm	Contact Width cm	Contact Pressure N/cm²
						4.00-7, 2-PR							
15	444	11.0	11.2	7.85	6.68	10.59	11.18	35.81	109	31.55	9.42	4.52	14.10
15	999	22.8	22.9	7.90	6.71	10.72	11.23	35.92	109	40.71	10.67	5.00	24.59
25	444	4.1	4.3	7.82	5.87	10.59	11.43	35.76	105	70.13	13.49	6.73	6.34
25	999	11.6	11.7	7.85	5.89	10.62	11.43	35.81	105	74.39	13.23	6.76	13.45
25	1511	17.8	17.9	7.90	5.92	10.67	11.61	35.92	105	74.71	13.43	6.93	20.24
35	444	1.7	1.9	7.87	5.11	10.49	11.71	35.86	102	101.68	15.75	[illegible]	4.38
35	999	7.0	7.2	7.85	5.11	10.59	11.89	35.81	102	100.32	15.37	8.28	9.97
35	2022	14.9	15.1	7.87	5.11	10.67	12.09	35.86	102	112.52	16.23	8.71	17.99
						4.00-20, 2-PR							
15	999	16.9	17.0	8.03	6.83	10.62	11.51	71.09	217	59.42	15.24	5.08	16.71
15	2022	33.1	33.2	8.18	6.96	10.72	11.28	71.40	218	63.10	16.10	5.08	32.08
25	999	7.7	7.9	7.92	5.94	10.44	11.51	70.89	213	105.22	18.69	6.99	9.52
25	1511	12.4	12.5	7.98	5.94	10.54	11.58	70.99	--	105.29	19.23	6.99	14.36
25	2022	16.8	17.0	8.03	6.02	10.62	11.58	71.09	213	106.25	19.17	6.91	19.05
25	2977	25.6	25.9	8.13	6.10	10.67	11.71	71.30	214	105.35	19.69	6.68	28.29
35	999	4.3	4.6	7.90	5.13	10.29	12.07	70.84	209	146.39	21.97	8.48	6.85
35	1511	7.6	7.6	7.92	5.16	10.44	12.24	70.89	--	158.71	22.86	8.69	9.53
35	2022	10.1	10.3	7.95	5.16	10.52	12.24	70.94	210	160.64	23.01	8.59	12.60
35	2977	15.6	15.9	8.03	5.18	10.59	12.27	71.09	210	164.64	23.22	8.69	18.10
						6.00-16, 2-PR							
15	999	5.7	5.9	13.39	11.38	16.76	17.53	71.78	215	131.74	18.29	8.38	7.59
15	2022	11.7	11.9	13.46	11.43	16.79	17.65	71.93	215	144.74	19.63	8.48	14.07
15	2977	19.9	20.0	13.51	11.48	16.81	17.78	72.03	216	132.39	19.23	8.20	22.55
15	3955	26.0	26.2	13.54	11.51	16.84	17.78	72.09	216	137.68	19.43	8.38	28.96
25	999	2.9	3.1	13.33	10.01	16.76	18.49	71.68	210	205.81	22.61	10.92	4.91
25	2022	6.9	7.1	13.39	10.03	16.76	18.34	71.78	210	219.03	23.88	10.80	9.24
25	3955	14.3	14.5	13.46	10.11	16.81	18.49	71.93	211	232.84	24.69	11.18	17.03
35	999	1.4	1.7	13.28	8.64	16.76	19.61	71.58	206	363.55	28.19	15.49	2.76
35	2022	4.5	4.8	13.39	8.71	16.76	19.56	71.78	206	324.19	28.45	13.02	6.24
35	2977	6.9	7.1	13.39	8.71	16.76	19.61	71.78	207	339.93	29.21	14.25	9.45
35	3955	8.6	9.0	13.44	8.74	16.76	19.61	71.88	207	366.19	30.18	14.55	11.03
						9.00-14, 2-PR							
15	999	5.0	5.2	16.05	13.61	20.96	21.59	71.63	213	171.61	20.32	10.54	5.83
15	2022	11.2	11.3	16.18	13.77	21.03	21.64	71.93	215	172.90	20.83	10.16	11.71
15	3955	25.3	25.5	16.61	14.12	21.13	21.87	72.80	221	154.19	20.24	9.53	25.68
25	999	2.1	2.2	16.00	11.99	20.88	22.25	71.58	--	344.52	27.84	15.39	2.90
25	2022	5.0	5.2	16.03	12.01	20.96	22.35	71.63	207	338.06	27.31	14.73	5.98
25	2977	6.0	6.1	16.15	12.12	20.98	22.40	71.88	--	327.10	27.03	14.61	9.11
25	3955	11.2	11.3	16.18	12.14	21.03	22.53	71.93	208	323.87	27.00	14.61	12.22
35	999	1.0	1.4	15.98	10.39	20.93	23.42	71.53	213	507.74	33.02	19.00	1.97
35	2977	5.0	5.2	16.03	10.41	20.96	23.80	71.63	203	488.39	32.46	18.14	6.10
35	3955	7.0	7.3	16.15	10.49	20.96	23.77	71.88	204	452.26	32.00	17.96	8.76

Table 2

Characteristics of Validation Test Tires

Deflection %	Load N	Inflation Pressure N/cm² No Load	Inflation Pressure N/cm² Loaded	Carcass Section Height, cm No Load	Carcass Section Height, cm Loaded	Section Width, cm No Load	Section Width, cm Loaded	Tire Diam cm	Measured Rolling Circumference cm	Hard Surface Measurements: Contact Area cm²	Contact Length cm	Contact Width cm	Contact Pressure N/cm²
1.75-26, Bicycle Tire													
15	444	27.8	29.0	3.56	3.02	4.37	4.67	71.55	199	14.19	9.91	1.78	31.30
15	999	62.7	64.3	3.56	3.02	4.50	4.80	71.55	199	15.48	10.41	2.03	63.30
35	444	8.5	9.2	3.56	2.31	4.29	5.13	71.55	196	3[illegible].35	15.49	3.05	11.17
35	999	22.8	24.0	3.56	2.31	4.37	5.11	71.55	196	38.06	14.99	3.05	26.20
16x15-6R, 2-PR Terra Tire													
15	999	4.7	4.8	12.70	10.80	38.61	38.61	43.18	131	161.29	21.34	8.38	6.21
15	2,022	12.1	12.2	13.41	11.40	38.61	38.61	44.60	136	133.55	20.83	7.62	15.17
15	3,199	21.3	21.4	13.97	11.89	38.61	38.61	45.72	140	145.81	20.07	9.14	21.93
25	999	2.0	2.1	12.29	9.22	38.61	38.61	42.37	129	328.39	27.69	12.95	3.0[illegible]
25	2,022	4.8	5.0	12.70	9.53	38.61	38.61	43.18	131	339.35	27.94	13.72	5.93
25	3,199	8.9	9.0	13.18	9.88	38.61	38.66	44.19	133	325.16	27.43	13.72	9.86
9.00-14, 2-PR													
25	1,289	3.9	4.1	14.40	10.80	21.64	22.40	68.10	205	278.06	22.61	14.73	4.62
25	2,022	6.2	6.5	14.61	10.95	21.54	22.48	68.50	206	30[illegible].81	23.37	15.75	6.62
25	2,977	9.4	9.7	14.76	11.07	21.59	22.30	68.91	208	304.52	24.38	14.99	9.72
25	3,955	--	12.1	14.83	11.13	21.95	22.86	68.96	209	312.26	24.64	15.24	12.62
25	5,911	20.5	20.8	15.34	11.51	22.50	23.11	69.98	213	295.48	24.64	14.22	20.00
11.00-20, 12-PR													
15	13,333	--	31.2	22.94	19.51	28.98	30.40	104.95	3807	381.29	29.06	15.37	35.03
15	19,999	--	43.4	22.94	19.51	29.36	30.76	104.95	3796	409.35	29.03	17.02	48.89
23	13,333	--	13.1	22.94	17.20	28.73	31.75	104.95	3652	674.32	39.07	20.42	19.79
35	13,333	--	7.8	22.94	14.91	28.42	33.10	104.95	3557	877.48	45.36	21.59	15.17
35	19,999	--	14.5	22.94	14.91	28.98	33.10	104.95	3537	912.58	45.42	22.07	21.93

Table 3

Single-Wheel Tests in Yuma Sand, 20 Percent Slip, First Pass, Basic Test Tires

Test No.	Penetration-Resistance Gradient, G N/cm²/cm	Deflection δ/h Design	Deflection δ/h Test	Wheel Load W, N Design	Wheel Load W, N Test	Pull P, N	Torque Q m·N	Slip s %	Sinkage z, cm	Pull Coefficient $\frac{P}{W}$	Torque Coefficient $\frac{Q}{r_e W}$	Sinkage Coefficient $\frac{z}{d}$	Strength-Load Ratio G/W cm^{-3}	Sand Loading Number $\frac{Gd^3}{W}$	Sand Number $\frac{G(bd)^{3/2}}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
4.00-7, 2-PR																
164 798A	5.3	0.15	0.128	444	368	79	24	20.1	1.64	0.217	0.376	0.046	0.024	658.59	105.92	13.56
164 824A	5.4	0.15	0.148	444	435	113	24	20.2	1.99	0.265	0.375	0.056	0.012	572.09	92.01	13.69
164 825A	3.1	0.15	0.165	444	500	71	32	20.2	3.15	0.142	0.366	0.088	0.006	285.28	45.88	7.57
164 799A	5.4	0.15	0.130	999	906	44	51	20.1	2.90	0.049	0.322	0.081	0.006	277.17	45.19	6.28
164 800A	4.2	0.15	0.140	999	913	39	52	19.8	3.29	0.044	0.325	0.092	0.005	212.72	34.68	4.86
164 801A	4.9	0.15	0.139	999	936	-13	51	21.1	3.82	-0.015	0.320	0.106	0.005	249.45	40.67	5.09
164 821A	3.4	0.15	0.138	999	897	22	60	20.0	4.00	0.025	0.382	0.111	0.004	174.95	28.52	3.94
164 807A	6.0	0.25	0.283	444	519	222	36	19.9	1.06	0.427	0.433	0.030	0.011	524.86	84.60	23.94
164 808A	6.5	0.25	0.203	444	528	271	41	20.0	1.64	0.513	0.493	0.046	0.012	562.95	90.73	26.59
164 831A	8.3	0.25	0.213	888	835	266	54	20.0	1.71	0.319	0.395	0.048	0.010	454.78	73.41	15.64
164 820A	3.5	0.25	0.256	999	1026	102	56	20.3	2.82	0.100	0.322	0.079	0.003	157.76	25.46	6.52
164 822A	4.3	0.25	0.236	999	937	177	52	19.4	1.68	0.190	0.339	0.047	0.005	212.57	34.31	8.10
164 819A	6.6	0.25	0.256	999	1026	235	99	18.7	1.50	0.229	0.347	0.042	0.006	297.31	47.99	12.29
164 82[illegible]	3.9	0.25	0.250	1511	1506	133	70	19.5	3.74	0.088	0.276	0.104	0.003	120.93	19.58	4.89
164 83[illegible]	6.2	0.35	0.350	444	471	208	37	20.4	0.85	0.443	0.510	0.024	0.013	619.84	96.63	34.69
164 834A	5.7	0.35	0.350	666	666	244	44	19.7	0.80	0.367	0.420	0.022	0.009	394.12	62.80	21.98
165 1A	7.5	0.35	0.318	666	635	235	48	19.7	1.62	0.371	0.478	0.045	0.012	541.38	87.83	29.69
164 830A	6.4	0.35	0.344	999	973	324	65	19.8	0.94	0.333	0.421	0.026	0.007	300.80	48.38	16.64
165 2A	1.5	0.35	0.329	999	906	-71	51	20.4	7.57	-0.078	0.325	0.211	0.002	75.58	12.16	4.00
164 832A	6.8	0.35	0.339	2022	1937	493	117	20.0	2.15	0.255	0.387	0.060	0.003	161.42	26.19	8.88
4.00-20, 2-PR																
164 790A	1.8	0.15	0.136	999	875	119	131	19.9	6.61	0.137	0.424	0.094	0.002	723.53	41.76	5.68
164 791A	2.6	0.15	0.143	999	937	173	120	20.0	4.39	0.185	0.364	0.062	0.003	987.30	56.98	8.15
164 793A	1.6	0.15	0.143	999	933	239	125	19.4	2.24	0.257	0.336	0.031	0.006	2140.64	123.54	17.67
164 788A	4.2	0.15	0.140	2022	1848	217	241	20.5	5.73	0.118	0.367	0.080	0.002	827.60	48.14	6.74
164 789A	2.0	0.15	0.136	2022	1786	32	239	19.4	10.27	0.035	0.377	0.144	0.001	414.40	24.10	3.28
164 792A	3.3	0.15	0.140	2022	1844	142	250	20.4	6.66	0.077	0.382	0.093	0.002	642.27	37.36	5.23
164 794A	4.1	0.15	0.143	2022	1888	253	243	20.7	4.30	0.134	0.364	0.060	0.002	783.94	45.60	6.52
164*795A	5.2	0.15	0.141	2022	1866	293	250	19.4	3.88	0.157	0.344	0.054	0.001	1004.82	58.45	8.24
165 14A	7.6	0.25	0.242	999	959	337	144	20.3	1.11	0.352	0.446	0.016	0.008	2818.28	159.26	38.54
165 15A	4.7	0.25	0.258	999	1035	355	150	19.8	1.59	0.343	0.430	0.022	0.005	1652.91	92.28	23.81
165 19A	5.0	0.25	0.243	1511	1462	457	198	19.7	2.03	0.313	0.387	0.029	0.003	1227.78	70.25	17.07
165 16A	4.1	0.25	0.241	2022	1911	413	243	20.4	3.08	0.216	0.369	0.043	0.002	764.95	44.15	10.64
165 17A	0.9	0.25	0.222	8977	2551	-262	344	20.4	18.15	-0.103	0.380	0.255	0.000	134.86	7.81	1.73
165 21A	8.0	0.35	0.354	999	1017	479	165	20.1	1.77	0.477	0.490	0.025	0.008	2794.68	154.65	54.75
165 23A	1.2	0.35	0.371	999	1093	133	147	19.4	7.79	0.122	0.389	0.110	0.001	396.85	21.96	8.15
165 22A	8.0	0.35	0.357	1511	1542	693	251	19.8	1.32	0.450	0.496	0.019	0.005	1848.30	104.45	37.29
165 20A	5.3	0.35	0.331	2022	1884	662	276	20.6	2.12	0.351	0.443	0.030	0.003	1002.03	57.10	18.93
165 18A	1.8	0.25	0.330	2177	2675	-102	392	20.1	14.52	-0.038	0.417	0.204	0.001	236.77	13.62	4.49
6.00-16, 2-PR																
164 802A	1.7	0.15	0.141	999	919	223	128	19.3	3.81	0.234	0.396	0.053	0.002	[illegible].89	77.53	10.93
164 805A	3.8	0.15	0.143	999	942	337	135	20.1	0.70	0.358	0.417	0.010	0.004	1490.42	168.22	24.05
164 809A	4.8	0.15	0.147	999	968	417	158	19.9	1.11	0.431	0.480	0.015	0.005	1832.43	206.82	30.40

(Continued)

Table 3 (Concluded)

Test No.	Penetration-Resistance Gradient, G N/cm²/cm	Deflection δ/h Design	Deflection δ/h Test	Wheel Load W, N Design	Wheel Load W, N Test	Pull P, N	Torque Q N-m	Slip s %	Sinkage z, cm	Pull Coefficient $\frac{P}{W}$	Torque Coefficient $\frac{Q}{r_e W}$	Sinkage Coefficient $\frac{z}{d}$	Strength-Load Ratio G/W cm^{-3}	Sand Loading Number $\frac{Gd^3}{W}$	Sand Number $\frac{G(bd)^{3/2}}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
									6.00-16, 2-PR (Continued)							
164 808A	3.9	0.15	0.139	1333	1235	417	174	19.7	1.79	0.338	0.409	0.025	0.003	1165.87	131.31	18.25
164 807A	3.2	0.15	0.145	2022	1968	462	265	19.6	3.26	0.235	0.386	0.045	0.002	584.50	65.91	9.56
164 804A	1.9	0.15	0.384	4977	2737	39	360	20.0	9.16	0.015	0.368	0.127	0.001	255.50	28.81	9.34
164 810A	2.5	0.15	0.143	3955	3724	128	490	19.9	7.96	0.035	0.368	0.110	0.001	248.22	28.03	4.01
164 816A	4.2	0.25	0.259	999	1039	493	188	20.0	1.47	0.474	0.536	0.021	0.004	1450.21	164.03	42.48
165 37A	4.6	0.25	0.244	999	973	457	170	19.5	0.85	0.470	0.532	0.012	0.005	1794.76	198.47	48.43
164 618A	5.0	0.25	0.246	2022	1986	897	311	21.2	1.66	0.432	0.479	0.023	0.002	923.97	104.28	25.65
164 819A	0.8	0.25	0.230	2022	1844	79	237	20.6	9.92	0.043	0.363	0.138	0.000	168.59	19.03	4.38
164 812A	4.3	0.25	0.241	3955	3742	924	467	19.6	3.28	0.247	0.375	0.046	0.001	423.51	47.86	11.54
164 817A	2.9	0.25	0.241	3955	3755	524	487	20.3	6.09	0.140	0.375	0.085	0.001	284.92	32.20	7.76
165 31A	1.0	0.25	0.233	3955	3573	-293	471	20.6	16.34	-0.082	0.369	0.227	0.000	104.53	11.81	2.75
164 803A	1.7	0.35	0.337	999	964	413	165	21.0	2.34	0.429	0.525	0.031	0.002	649.69	73.64	24.82
164 813A	5.3	0.35	0.368	999	1057	528	178	20.0	0.71	0.500	0.537	0.010	0.005	1824.10	206.75	76.09
164 814A	5.3	0.35	0.340	2022	1954	946	335	20.2	0.86	0.484	0.543	0.012	0.003	995.10	112.31	38.19
164 815A	1.5	0.35	0.380	2977	2719	297	363	19.8	8.85	0.109	0.394	[illegible] 123	0.001	199.14	22.40	7.19
164 811A	4.?	0.35	0.334	3955	[illegible]59	1133	512	20.1	2.97	0.301	0.489	0.041	0.001	428.66	48.24	16.12
									9.00-14, 2-PR							
164 778A	[illegible]	0.15	0.147	999	977	5	149	20.0	2.03	0.364	0.424	0.028	0.002	917.42	145.17	21.34
164 779A	1.8	0.15	0.143	999	942	297	131	20.0	2.68	0.316	0.406	0.037	0.002	687.58	108.80	15.56
164 780A	4.1	0.15	0.151	999	1008	453	163	19.7	2.09	0.449	0.481	0.029	0.004	1481.88	234.49	35.41
164 786A	5.3	0.15	0.152	999	1008	493	187	19.6	1.71	0.489	0.539	0.024	0.005	1926.44	304.83	46.03
164 774A	1.6	0.15	0.145	2022	1942	266	258	20.0	5.85	0.137	0.377	0.082	0.001	311.85	49.30	7.15
164 777A	2.6	0.15	0.190	2022	1964	493	264	20.0	3.71	0.251	0.388	0.052	0.001	488.18	77.18	11.58
164 782A	3.5	0.15	0.147	2022	1982	595	270	20.0	2.99	0.300	0.399	0.042	0.002	662.05	104.66	15.39
164 783A	1.5	0.15	0.140	2022	1844	319	266	19.7	6.30	0.173	0.410	0.088	0.001	301.02	47.59	6.66
164 784A	5.4	0.15	0.148	2022	1991	746	299	20.1	2.31	0.373	0.442	0.032	0.003	1013.99	159.43	23.60
164 775A	1.7	0.15	0.141	3955	3697	22	407	16.7	9.60	0.006	0.372	0.132	0.000	180.21	28.19	3.97
164 776A	2.8	0.15	0.145	3955	3786	306	484	19.8	6.40	0.081	0.359	0.088	0.001	284.59	44.51	6.45
164 781A	3.5	0.15	0.144	3955	3737	639	475	20.0	5.07	0.171	0.460	0.070	0.001	358.30	56.04	8.07
164 785A	5.2	0.15	0.144	3955	3728	835	476	20.4	3.42	0.224	0.366	0.047	0.001	538.73	84.26	12.13
164 787A	2.5	0.15	0.139	3955	3617	279	512	20.6	8.02	0.077	0.394	0.110	0.001	266.07	41.62	5.78
165 3A	3.2	0.25	0.236	666	626	364	121	19.9	0.76	0.582	0.603	0.011	0.005	1833.18	290.84	68.64
165 4A	3.5	0.25	0.244	999	973	479	177	19.7	1.15	0.493	0.59?	0.016	0.004	1307.94	206.06	50.28
165 7A	6.6	0.25	0.241	999	959	942	176	19.7	0.56	0.565	0.569	0.008	0.007	2538.26	399.88	90.37
165 6A	3.9	0.25	0.228	2022	1919	893	326	20.5	1.91	0.465	0.526	0.027	0.002	752.72	119.11	27.16
165 27A	3.7	0.25	0.230	2022	2017	924	337	20.3	1.86	0.458	0.520	0.026	0.002	681.66	107.86	26.97
165 3A	0.9	0.25	0.233	2977	2746	88	379	20.0	10.41	0.032	0.393	0.144	0.000	130.00	20.52	4.78
165 25A	0.8	0.25	0.233	2977	2745	44	371	20.0	10.40	0.016	0.385	0.145	0.000	102.69	16.19	3.77
165 26A	0.7	0.25	0.236	2977	2782	-17	383	20.4	12.07	-0.006	0.390	0.158	0.000	90.52	14.27	3.37
165 28A	0.9	0.25	0.242	2977	2871	88	402	20.1	10.18	0.031	0.401	0.142	0.000	122.80	19.36	4.69
165 3A	4.2	0.25	0.237	3955	3688	1324	532	20.1	1.50	0.359	0.447	0.022	0.001	424.16	67.06	15.09
165 24A	4.8	0.25	0.240	3955	3733	1457	579	19.9	1.86	0.390	0.482	0.026	0.001	481.31	76.09	18.26
165 9A	6.1	0.35	0.373	999	1079	613	215	20.1	0.?1	0.568	0.648	0.007	0.006	2067.64	324.90	121.19
165 11A	4.1	0.35	0.352	999	1008	559	189	20.6	0.41	0.555	0.602	0.006	0.004	1475.58	231.86	81.32
165 18A	7.5	0.35	0.348	2977	2999	1422	490	20.0	2.17	0.480	0.536	0.030	0.003	985.99	142.53	30.99
165 13A	3.1	0.35	0.334	2977	2817	506	368	20.4	6.89	0.180	0.399	0.096	0.000	141.49	22.39	7.48
165 10A	3.7	0.35	0.344	3955	3857	1533	562	20.3	1.40	0.397	0.484	0.020	0.001	360.35	56.72	19.51

Table 4

Single-Wheel Tests in Yuma Sand, Towed Point, First Pass, Basic Test Tires

Test No.	Penetration-Resistance Gradient, G $N/cm^2/cm$	Deflection δ/h Design	Deflection δ/h Test	Wheel Load W, N Design	Wheel Load W, N Test	Pull P, N	Slip S %	Sinkage z, cm	Pull Coefficient $\frac{P}{W}$	Sinkage Coefficient $\frac{z}{d}$	Strength-Load Ratio $\frac{G}{W}$ cm^{-2}	Sand Loading Number $\frac{Gd^3}{W}$	Sand Number $\frac{G(bd)^{3/2}}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
							4.00-7, 2-PR							
164 788A	5.3	0.15	0.131	444	377	-97	-7.5	0.96	-0.259	0.027	0.014	643.09	103.43	13.55
164 824A	5.4	0.15	0.146	444	471	-53	-3.1	1.32	-0.113	0.037	0.012	528.91	85.07	13.27
164 825A	3.1	0.15	0.175	444	546	-93	-7.0	2.47	-0.171	0.069	0.006	262.09	42.15	7.38
164 800A	4.2	0.15	0.142	999	933	-284	-12.4	1.87	-0.305	0.052	0.005	208.67	34.00	4.83
164 827A	6.0	0.25	0.301	444	537	-15	-2.5	0.70	-0.025	0.006	0.011	507.51	81.80	24.62
165 578A	6.5	0.25	0.304	444	542	-17	-1.2	1.32	-0.033	0.037	0.012	540.11	88.50	[illegible]
164 831A	8.3	0.25	0.210	888	822	-104	-5.7	0.98	-0.130	0.027	0.010	462.15	74.60	15.67
164 822A	4.3	0.25	0.241	999	959	-133	-4.2	0.86	-0.139	0.025	0.005	207.65	33.52	8.08
164 829A	6.6	0.25	0.259	999	1039	-111	-2.0	0.50	-0.107	0.014	0.006	297.50	47.37	12.27
164 826A	3.9	0.25	0.256	1511	1546	-324	-7.0	2.95	-0.210	0.082	0.003	117.80	19.07	4.88
164 833A	6.2	0.35	0.363	444	484	-57	-4	0.20	-0.119	0.006	0.013	594.03	93.07	34.11
164 834A	5.7	0.35	0.354	666	675	-57	-3.9	0.10	-0.086	0.003	0.008	358.94	61.97	21.94
165 1A	7.5	0.35	0.350	666	644	-64	-3.9	0.75	-0.103	0.021	0.012	533.31	86.61	30.32
164 830A	6.4	0.35	0.350	999	995	-75	-3.8	0.15	-0.076	0.004	0.006	294.04	47.30	16.55
164 832A	6.8	0.35	0.342	2022	1955	-244	-3.0	1.23	-0.125	0.034	0.003	155.75	[illegible]	8.87
							4.00-20, 2-PR							
164 791A	2.6	0.15	0.147	900	965	-204	-11.	3.3	-0.211	0.047	0.003	351.60	55.15	8.11
164 793A	5.6	0.15	0.148	909	989	-124	-1.9	1.51	-0.118	0.021	0.006	2034.03	117.39	17.37
164 788A	4.2	0.15	0.143	2022	1991	-466	-10.6	4.58	-0.246	0.064	0.002	608.7	47.01	6.72
164 794A	4.1	0.15	0.147	2022	1955	-444	-9.2	3.05	-0.227	0.042	0.002	757.72	44.05	6.47
164 795A	5.2	0.15	0.148	2022	1982	-386	-7.6	3.42	-0.195	0.044	0.003	944.2	54.06	8.15
165 14A	7.6	0.25	0.251	999	1008	-79	-2.6	0.00	-0.074	0.000	0.008	2681.71	151.54	38.04
165 15A	4.7	0.25	0.263	999	1057	-48	-2.0	0.74	-0.046	0.011	0.004	1548.60	90.34	23.76
165 19A	[illegible]	0.25	0.249	1511	1502	-93	-1.9	0.65	-0.062	0.009	0.003	1195.09	68.38	17.01
165 16A	4.1	0.25	0.247	2022	1999	-311	-2.0	1.96	-0.156	0.028	0.002	730.95	42.18	10.42
165 21A	8.0	0.35	0.358	999	1035	-66	-2.7	0.00	-0.064	0.014	0.008	2746.75	151.00	54.41
165 22A	8.0	0.35	0.360	1511	1555	-44	-1.8	0.60	-0.029	0.009	0.005	1832.46	103.55	37.29
165 20A	5.3	0.35	0.343	2022	1964	-93	-0.9	0.65	-0.046	0.009	0.003	961.23	54.86	18.82
							6.00-16, 2-PR							
164 802A	1.7	0.15	0.144	999	946	-145	-8.8	2.59	-0.155	0.036	0.002	667.54	75.34	10.85
164 805A	3.8	0.15	0.145	999	955	-66	-2.8	0.00	-0.070	0.000	0.004	1469.62	165.87	24.05
164 806A	4.8	0.15	0.149	999	986	-57	-2.6	0.50	-0.059	0.007	0.005	1799.44	203.09	30.26
164 808A	3.9	0.15	0.147	1333	1309	-84	-2.6	0.50	-0.064	0.007	0.003	1106.18	124.58	18.31
164 807A	3.1	0.15	0.150	2022	2035	-266	-3.3	2.43	-0.131	0.034	0.002	565.25	63.75	9.56
165 33A	1.2	0.15	0.147	2977	2888	-1297	-37.6	8.96	-0.449	0.124	0.000	161.42	18.21	2.68
164 816A	4.1	0.25	0.264	999	1066	-44	-1.3	0.70	-0.042	0.010	0.004	1413.96	159.93	42.22
165 37A	4.6	0.25	0.248	999	991	-62	-1.3	0.10	-0.063	0.001	0.005	1723.31	194.91	48.34
164 818A	5.0	0.25	0.250	2022	2022	-79	-3.3	0.75	-0.040	0.011	0.002	907.73	102.45	25.61
165 33A	0.7	0.25	0.238	2022	1906	-808	-39.3	9.05	-0.424	0.126	0.000	136.78	15.44	3.67
164 812A	4.3	0.25	0.245	3955	3844	-337	-9.2	1.79	-0.088	0.025	0.001	412.25	46.59	11.42
164 817A	2.9	0.25	0.245	3955	3835	-768	-8.1	3.92	-0.200	0.054	0.001	278.98	31.53	7.72
164 803A	1.7	0.35	0.350	999	999	-115	-4.5	1.30	-0.116	0.018	0.002	626.99	71.02	24.86
164 813A	5.3	0.35	0.369	999	1062	-48	-1.1	0.41	-0.046	0.006	0.005	1816.46	205.69	75.97
164 814A	5.3	0.35	0.344	2022	1982	-35	-1.3	0.10	-0.018	0.001	0.003	931.71	110.80	38.12
165 34A	1.0	0.35	0.352	2977	2995	-1093	-30.9	9.14	-0.367	0.127	0.000	123.90	13.98	4.92
164 811A	4.3	0.35	0.343	3955	3866	-213	-2.3	0.86	-0.055	0.012	0.001	416.83	46.95	16.10
							9.00-14, 2-PR							
164 775A	2.4	0.15	0.152	999	1022	-53	-2.7	0.60	-0.052	0.008	0.002	877.53	138.86	21.11
164 779A	1.8	0.15	0.150	999	939	-93	-4.7	1.49	-0.098	0.021	0.002	647.86	102.51	15.38
164 780A	4.1	0.15	0.152	999	1022	-75	-4.2	1.08	-0.074	0.015	0.004	1462.55	231.43	35.18
164 786A	5.3	0.15	0.153	999	1031	-26	-2.2	1.06	-0.026	0.015	0.005	1884.92	298.26	45.63
164 777A	2.6	0.15	0.152	2022	2044	-231	-4.7	2.62	-0.113	0.036	0.001	469.08	74.16	11.27
164 782A	3.5	0.15	0.131	2022	2035	-137	-2.5	1.83	-0.068	0.025	0.002	644.70	101.92	15.39
164 783A	1.5	0.15	0.145	2022	1937	-417	-11.9	4.62	-0.216	0.064	0.001	286.52	45.30	6.57
164 785A	5.4	0.15	0.152	2022	2044	-93	-2.6	1.17	-0.046	0.016	0.003	987.53	155.27	23.60
164 781A	3.5	0.15	0.148	3955	3871	-684	-4.2	4.05	-0.177	0.056	0.001	345.96	54.11	8.01
164 784A	5.2	0.15	0.147	3955	3829	-328	-0.9	2.22	-0.085	0.031	0.001	523.14	81.85	12.03
165 5A	3.2	0.25	0.241	665	639	-31	-0.5	0.00	-0.049	0.000	0.005	1794.99	284.78	68.63
165 4A	3.5	0.25	0.250	999	999	-31	-2.0	0.46	-0.031	0.006	0.003	1273.06	200.56	50.14
165 7A	6.6	0.25	0.241	999	999	-26	-0.8	0.46	-0.078	0.006	0.007	2538.26	399.88	96.37
165 6A	3.9	0.25	0.246	2022	1982	-124	-2.4	1.10	-0.063	0.015	0.002	729.09	115.37	28.38
165 27A	3.7	0.25	0.254	2022	2066	-66	-3.4	1.00	-0.032	0.014	0.002	665.54	105.31	26.75
165 26A	0.9	0.25	0.245	2977	2915	-1124	-29.7	7.75	-0.386	0.106	0.000	120.93	19.07	4.67
165 3A	8.2	0.25	0.242	3955	3777	-33	-1.7	0.05	-0.035	0.001	0.001	414.18	65.48	15.85
165 24A	4.8	0.25	0.244	3955	3831	-55	-2.9	0.46	-0.042	0.006	0.001	469.22	74.15	18.09
165 9A	6.1	0.35	0.373	999	1079	-79	0.4	0.46	-0.074	0.006	0.006	2067.64	324.90	121.19
165 11A	4.1	0.35	0.351	999	1004	-57	0.2	0.05	-0.056	0.001	0.004	1482.11	232.89	81.74
165 12A	7.5	0.35	0.349	2977	2968	-97	-0.6	0.00	-0.033	0.000	0.003	923.12	146.09	50.98
165 13A	1.1	0.35	0.343	2977	2962	-573	-13.8	5.18	-0.198	0.072	0.000	137.37	21.74	7.46
165 12A	3.7	[illegible]	0.351	3955	3964	-173	-0.9	0.61	-0.044	0.008	0.001	379.65	55.19	19.37

Table 5

Single-Wheel Tests in Yuma Sand, 20 Percent Slip, First Pass, Validation Test Tires

Test No.	Penetration-Resistance Gradient, G $N/cm^2/cm$	Wheel Load W	Design Deflection $\frac{\delta}{h}$	Pull Coefficient $\frac{P}{W}$	Sinkage Coefficient $\frac{z}{d}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
			1.75-26, Bicycle Tire			
161 499A	5.4	444	0.15	0.152	0.044	9.0
161 504A	2.7	444	0.15	0.148	0.071	6.0
161 510A	6.5	444	0.15	0.231	0.025	13.0
161 497A	4.3	999	0.15	0.053	0.088	4.0
161 503A	3.5	999	0.15	-0.030	0.160	3.0
161 508A	2.7	999	0.15	-0.005	0.154	2.0
161 511A	7.3	999	0.15	0.119	0.056	6.0
161 500A	5.4	444	0.35	0.250	0.034	22.0
161 502A	2.2	444	0.35	0.110	0.083	10.0
161 505A	2.7	444	0.35	0.131	0.072	12.0
161 498A	4.6	999	0.35	0.080	0.075	9.0
161 501A	1.9	999	0.35	0.000	0.162	4.0
161 506A	2.4	999	0.35	0.020	0.162	5.0
161 507A	3.8	999	0.45	0.051	0.080	7.0
161 509A	2.7	999	0.35	0.000	0.142	5.0
			9.00-14, 2-PR			
160 243A	1.9	1,289	0.25	0.348	0.028	22.3
161 345A	2.7	1,289	0.25	0.409	0.021	30.5
161 253A	4.0	1,289	0.25	0.466	0.011	44.0
161 261A	5.4	1,289	0.25	0.433	0.007	58.8
161 344A	2.6	2,022	0.25	0.362	0.021	19.1
161 252A	3.5	2,022	0.25	0.393	0.017	25.6
161 331A	4.4	2,022	0.25	0.432	0.004	31.2
161 245A	2.1	2,022	0.25	0.261	0.052	15.4
161 335A	2.1	2,022	0.25	0.290	0.042	14.9
161 348A	5.7	2,022	0.25	0.423	0.010	40.8
161 267A	5.8	2,022	0.25	0.409	0.008	40.8
161 250A	3.8	2,978	0.25	0.323	0.021	19.1
161 341A	2.8	2,978	0.25	0.286	0.047	14.2
161 262A	5.8	2,978	0.25	0.382	0.021	29.1
161 332A	4.7	2,978	0.25	0.388	0.014	23.3
160 238A	1.6	2,978	0.25	0.126	0.075	7.8
161 248A	1.9	3,956	0.25	0.158	0.079	7.1
161 343A	2.6	3,956	0.25	0.201	0.056	9.9
160 234A	3.9	3,956	0.25	0.277	0.029	14.5
160 242A	2.2	3,956	0.25	0.093	0.097	7.9
161 264A	5.9	3,956	0.25	0.355	0.024	21.3
160 240A	1.6	5,911	0.25	-0.069	0.157	4.3
161 244A	2.1	5,911	0.25	-0.024	0.124	5.0
161 260A	5.5	5,911	0.25	0.257	0.041	13.3
161 349A	2.9	5,911	0.25	0.112	0.074	7.0
161 350A	3.2	5,911	0.25	0.145	0.075	7.7
160 236A	4.2	5,911	0.25	0.179	0.043	11.1
			16x1½-6R, 2-PR Terra Tire			
162 645A	1.0	999	0.15	0.234	0.082	10.0

(Continued)

Table 5 (Concluded)

Test No.	Penetration-Resistance Gradient, G $N/cm^2/cm$	Wheel Load N	Design Deflection $\frac{\delta}{h}$	Pull Coefficient $\frac{P}{W}$	Sinkage Coefficient $\frac{z}{d}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
			16x15-6R, 2-PR Terra Tire (Continued)			
162 646A	1.6	999	0.15	0.338	0.041	18.0
162 650A	4.6	999	0.15	0.450	0.029	48.0
162 647A	1.3	2,022	0.15	0.072	0.096	7.0
162 648A	2.[illegible]	2,022	0.15	0.229	0.052	12.0
162 649A	3.7	2,022	0.15	0.310	0.046	19.0
162 651A	1.2	3,199	0.15	--	--	--
162 652A	2.2	3,199	0.15	0.150	0.066	7.0
162 653A	4.8	3,199	0.15	0.211	0.053	16.0
162 654A	2.0	3,199	0.15	0.127	0.079	6.0
162 658A	1.4	999	0.25	0.335	0.050	25.0
162 659A	2.2	999	0.25	0.557	0.038	37.0
162 662A	5.9	999	0.25	0.538	0.021	100.0
162 657A	1.2	2,022	0.25	0.210	0.081	10.0
162 660A	2.2	2,022	0.25	0.400	0.040	18.0
162 661A	5.4	2,022	0.25	0.475	0.021	47.0
162 655A	2.1	3,199	0.25	0.289	0.054	11.0
162 656A	1.2	3,199	0.25	-0.012	0.148	6.0
162 663A	5.3	3,199	0.25	0.353	0.039	28.0
263 25A	4.8	13,333	0.15	0.076	0.076	8.8
263 26A	4.3	13,333	0.15	0.055	0.082	7.9
263 27A	3.5	13,333	0.15	0.037	0.103	6.4
263 28A	2.8	13,333	0.15	0.035	0.111	5.1
263 29A	1.6	13,333	0.15	0.004	0.124	3.0
263 41A	5.3	13,333	0.15	0.097	0.081	9.8
263 42A	3.0	13,333	0.15	0.041	0.097	5.6
263 43A	1.7	13,333	0.15	0.004	0.131	3.2
263 44A	5.2	19,999	0.15	0.026	0.120	6.4
263 45A	4.0	19,999	0.15	0.006	0.122	4.9
263 46A	3.8	19,999	0.15	-0.026	0.123	4.8
263 47A	3.1	19,999	0.15	-0.054	0.146	3.8
263 48A	2.0	19,999	0.15	-0.076	0.153	2.5
			11.00-20, 12-PR			
263 30A	4.3	13,333	0.23	0.236	0.057	10.9
263 31A	3.9	13,333	0.23	0.158	0.064	10.0
263 32A	3.5	13,333	0.23	0.172	0.076	8.9
263 33A	3.1	13,333	0.23	0.170	0.081	7.8
263 34A	2.7	13,333	0.23	0.127	0.088	6.9
263 35A	1.7	13,333	0.23	0.060	0.097	4.4
263 36A	4.3	13,333	0.35	0.330	0.050	36.6
263 37A	4.4	13,333	0.35	0.295	0.044	17.0
263 38A	4.0	13,333	0.35	0.310	0.055	15.6
263 39A	3.1	13,333	0.35	0.299	0.050	12.1
263 40A	1.9	13,333	0.35	0.222	0.093	7.3
263 49A	5.0	19,999	0.35	0.239	0.054	14.3
263 50A	4.2	19,999	0.35	0.203	0.067	11.9
263 51A	3.3	19,999	0.35	0.197	0.087	9.5
263 52A	3.1	19,999	0.35	0.169	0.103	9.0
263 53A	2.0	19,999	0.35	0.115	0.133	5.6

Table 6

Single-Wheel Tests in Yuma Sand, 20 Percent Slip, Second Pass, Basic Test Tires

Test No.	Penetration-Resistance Gradient, G N/cm²/cm	Deflection δ/h Design	Deflection δ/h Test	Wheel Load W, N Design	Wheel Load W, N Test	Pull P, N	Torque Q m-N	Slip s %	Sinkage z, cm	Pull Coefficient P/W	Torque Coefficient $\frac{Q}{r_e W}$	Sinkage Coefficient z/d	Strength-Load Ratio G/W cm^{-3}	Sand Loading Number $\frac{Gd^3}{W}$	Sand Number $\frac{G(bd)^{3/2}}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
4.00-7, 2-PR																
164 798A	5.3	0.15	0.138	444	399	62	27	20.1	1.61	0.156	0.352	0.045	0.013	607.36	97.68	13.48
164 824A	5.4	0.15	0.132	444	417	106	23	20.0	0.99	0.255	0.313	0.028	0.013	596.43	95.93	12.66
164 825A	3.1	0.15	0.166	444	505	57	31	19.8	1.99	0.114	0.346	0.056	0.006	282.78	45.48	7.55
164 799A	5.4	0.15	0.134	999	871	22	54	19.9	2.37	0.026	0.350	0.066	0.006	288.48	47.03	6.30
164 800A	4.2	0.15	0.138	999	893	22	50	19.8	2.49	0.025	0.315	0.069	0.005	218.01	35.54	91
164 821A	7.4	0.15	0.137	999	879	0	52	19.9	2.55	0.000	0.338	0.071	0.004	178.48	29.10	[illegible].99
164 827A	6.0	0.25	0.250	444	448	133	25	19.9	0.55	0.297	0.341	0.015	0.013	608.01	98.00	24.50
164 828A	6.5	0.25	0.268	444	466	159	32	20.0	0.10	0.343	0.417	0.00	0.014	638.01	102.83	27.56
164 831A	8.3	0.25	0.230	888	799	164	46	20.5	1.42	0.206	0.342	0.040	0.010	474.99	76.67	17.63
164 820A	3.5	0.25	0.230	999	906	26	46	19.7	3.11	0.029	0.289	0.087	0.004	176.64	28.83	6.63
164 822A	4.3	0.25	0.225	999	885	66	46	19.8	2.45	0.075	0.297	0.068	0.005	224.26	36.20	8.14
164 829A	6.6	0.25	0.249	999	991	128	56	20.6	2.28	0.130	0.333	0.064	0.007	307.98	49.71	12.46
164 826A	3.9	0.25	0.234	1511	1435	17	73	19.8	3.24	0.012	0.295	0.090	0.003	126.92	20.55	4.81
164 833A	6.2	0.35	0.335	444	399	159	28	19.7	0.45	0.400	0.440	0.013	0.016	[illegible]	133.81	38.12
164 834A	5.7	0.35	0.344	666	653	182	40	19.7	1.49	0.279	0.381	0.042	0.009	402.17	64.08	22.03
165 1A	7.5	0.35	0.339	666	639	213	41	19.7	1.27	0.333	0.406	0.035	0.012	547.62	87.22	29.57
164 830A	6.4	0.35	0.337	999	946	222	51	19.8	1.40	0.235	0.335	0.039	0.007	309.28	49.74	16.76
165 2A	1.5	0.35	0.318	999	884	8	44	20.4	2.36	0.010	0.292	0.066	0.002	77.48	12.45	3.94
164 832A	6.8	0.35	0.327	2022	1879	159	79	20.0	3.12	0.085	0.262	0.087	0.004	166.48	26.99	8.63
4.00-20, 2-PR																
164 790A	1.8	0.15	0.138	999	888	182	117	19.9	1.81	0.205	0.375	0.024	0.002	712.68	41.17	5.68
164 791A	2.6	0.15	1.134	999	857	199	109	20.0	2.36	0.233	0.363	0.033	0.003	1079.38	62.29	[illegible]
164 793A	5.6	0.15	0.140	999	911	235	117	20.1	2.05	0.259	0.367	[illegible]	0.006	2192.85	126.55	[illegible]
164 788A	4.2	0.15	0.140	2022	1839	248	230	20.0	3.25	0.135	0.353	[illegible]	0.002	831.60	48.37	6.77
164 789A	2.0	0.15	0.136	2022	1793	182	218	20.6	11.34	0.107	0.343	0.159	0.001	413.37	24.04	3.27
164 792A	3.3	0.15	0.140	2022	1839	226	243	19.9	3.11	0.123	0.373	0.043	0.002	643.82	37.45	5.24
164 794A	4.1	0.15	0.136	2022	1786	264	228	20.0	2.90	0.159	0.364	0.041	0.002	828.80	48.21	6.56
164 795A	5.2	0.15	0.142	2022	1875	288	230	20.3	3.15	0.154	0.346	0.044	0.003	1000.05	58.17	8.25
165 14A	7.6	0.25	0.237	999	933	297	124	19.7	1.58	0.319	0.392	0.022	0.008	2898.60	163.81	36.82
165 15A	4.7	0.25	0.250	999	999	297	138	19.4	0.50	0.298	0.403	0.007	0.005	1690.97	95.56	23.89
165 19A	5.0	0.25	0.238	1511	1422	328	165	20.3	2.25	0.231	0.337	0.032	0.004	1262.31	72.22	17.19
165 16A	4.1	0.25	0.239	2022	1893	328	230	20.2	3.28	0.174	0.350	0.046	0.002	772.13	44.56	10.65
165 17A	0.9	0.25	0.228	2977	2679	26	311	19.7	0.00	0.010	0.334	0.000	0.000	130.32	7.54	1.72
165 21A	8.0	0.35	0.340	999	964	382	143	20.0	1.27	0.396	0.446	0.018	0.008	2849.22	163.20	55.49
165 23A	1.2	0.35	0.363	999	1057	262	132	20.0	1.09	0.248	0.372	0.015	0.001	410.19	22.70	8.24
165 22A	8.0	0.35	0.344	1511	1472	502	199	19.7	1.41	0.340	0.404	0.020	0.005	1931.81	109.17	37.55
165 20A	5.3	0.35	0.329	2022	1866	497	243	20.7	2.65	0.267	0.394	0.037	0.003	1011.58	57.73	18.99
165 18A	1.8	0.35	0.332	2977	2693	182	325	20.2	0.00	0.068	0.347	0.000	0.001	235.21	13.53	4.45
6.00-16, 2-PR																
164 802A	1.7	0.15	0.141	999	919	195	115	20.1	2.12	0.213	0.354	0.030	0.002	686.89	77.53	10.93
164 805A	3.8	0.15	0.141	999	915	271	119	20.3	1.54	0.296	0.373	0.021	0.004	1533.83	173.12	24.42
164 809A	4.8	0.15	0.141	999	924	293	124	20.5	1.02	0.317	0.390	0.014	0.005	1920.55	216.76	30.56
164 808A	3.9	0.15	0.137	1333	1231	306	153	20.0	1.79	0.249	0.356	0.023	0.003	1170.03	131.78	18.05

(Continued)

Table 6 (Concluded)

Test No.	Penetration-Resistance Gradient, G N/cm²/cm	Deflection b/h Design	Deflection b/h Test	Wheel Load W, N Design	Wheel Load W, N Test	Pull P, N	Torque Q m-N	Slip s %	Sinkage z, cm	Pull Coefficient $\frac{P}{W}$	Torque Coefficient $\frac{Q}{r_e W}$	Sinkage Coefficient $\frac{z}{d}$	Strength-Load Ratio G/W cm^{-3}	Sand Loading Number $\frac{Gd^3}{W}$	Sand Number $\frac{G(bd)^{3/2}}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
									6.00-16, 2-PR (Continued)							
164 807A	3.1	0.15	0.140	2022	1919	319	239	20.0	3.13	0.164	0.347	0.044	0.002	999.38	67.59	9.46
164 824A	1.9	0.15	0.138	2977	2693	151	311	19.9	3.01	0.056	0.324	0.042	0.001	259.71	29.29	4.04
164 810A	2.5	0.15	0.140	3955	3666	177	438	20.2	4.03	0.048	0.335	0.056	0.001	252.13	28.47	3.99
164 816A	4.1	0.25	0.262	999	1053	422	165	19.8	0.75	0.401	0.473	0.011	0.004	1431.86	161.95	42.43
165 37A	4.6	0.25	0.241	999	959	386	149	19.5	0.80	0.403	0.466	0.011	0.005	1779.15	201.23	48.50
164 818A	5.0	0.25	0.241	2022	1933	631	265	19.9	1.47	0.326	0.413	0.021	0.003	949.46	107.16	25.83
164 819A	0.8	0.25	0.233	2022	1857	266	209	19.5	1.33	0.144	0.326	0.019	0.000	167.38	18.89	4.40
164 812A	4.3	0.25	0.238	3955	3697	533	438	20.3	3.81	0.144	0.345	0.053	0.001	428.60	48.44	11.53
164 817A	2.9	0.25	0.241	3955	3755	377	440	20.3	4.35	0.10[illegible]	0.338	0.061	0.001	284.92	32.20	7.76
164 803A	1.7	0.35	0.336	999	951	369	149	19.9	1.01	0.388	0.477	0.014	0.002	658.79	74.67	[illegible]
164 813A	5.3	0.35	0.360	999	1044	475	177	19.3	0.71	0.455	0.532	0.010	0.005	1847.38	209.39	75.38
164 814A	5.3	0.35	0.341	2022	1964	759	292	20.3	1.30	0.387	0.461	0.018	0.003	990.59	111.80	38.12
164 815A	1.5	0.35	0.318	2977	2711	484	325	19.3	3.08	0.179	0.360	0.043	0.002	199.79	22.55	7.17
164 811A	4.3	0.35	0.334	3955	3782	804	453	20.1	3.70	0.213	0.371	0.051	0.001	426.14	47.93	16.03
									9.00-14, 2-PR							
164 776A	2.4	0.15	0.147	999	973	293	130	19.7	1.08	0.301	0.387	0.015	0.003	921.61	145.83	21.44
164 779A	1.8	0.15	0.145	999	955	271	130	20.0	1.80	0.284	0.393	0.025	0.002	677.99	107.28	15.56
164 780A	4.1	0.15	0.149	999	995	342	136	19.7	0.85	0.344	0.401	0.012	0.004	1501.73	237.63	35.41
164 786A	5.3	0.15	0.149	995	991	373	147	21.1	0.60	0.377	0.438	0.008	0.005	1961.00	310.30	46.23
164 774A	1.6	0.15	0.142	2022	1893	306	251	19.6	2.59	0.162	0.379	0.036	0.001	319.91	50.57	7.18
164 777A	2.6	0.15	0.143	2022	1915	373	254	20.6	2.66	0.195	0.379	0.037	0.001	500.64	79.15	11.32
164 780A	3.[illegible]	0.15	0.143	2022	1902	471	261	20.2	1.75	0.248	0.395	0.024	0.002	689.89	109.06	15.60
164 783A	1.5	0.15	0.140	2022	1848	315	241	19.5	2.55	0.171	0.369	0.035	0.001	300.30	47.47	6.65
164 785A	5.4	0.15	0.146	2022	1955	453	260	20.6	1.53	0.232	0.382	0.021	0.003	1032.42	162.33	23.70
164 772A	1.7	0.15	0.139	3955	3595	235	461	19.6	3.58	0.066	0.358	0.049	0.000	183.32	28.67	3.99
164 776A	2.8	0.15	0.144	3955	3746	319	460	19.3	4.02	0.085	0.343	0.055	0.001	287.63	44.99	6.48
164 701A	3.5	0.15	0.144	3955	3719	422	461	21.2	3.89	0.114	0.348	0.053	0.001	360.01	56.31	8.11
164 784A	5.2	0.15	0.144	3955	3791	542	457	19.9	2.75	0.145	0.344	0.038	0.001	535.53	83.76	12.06
164 787A	2.5	0.15	0.137	3955	3555	297	447	20.0	3.28	0.084	0.350	0.045	0.001	270.72	42.34	5.80
165 5A	3.2	0.25	0.235	666	622	315	108	19.6	0.15	0.507	0.529	0.00[illegible]	0.005	1844	292.92	68.84
165 4A	3.5	0.25	0.243	999	968	426	158	20.3	0.71	0.440	0.493	0.010	0.004	[illegible]	207.00	50.30
165 7A	6.6	0.25	0.240	999	955	475	185	20.3	0.00	0.408	0.592	0.000	[illegible]007	2550.06	401.74	96.42
165 6A	3.9	0.25	0.231	2022	1928	684	281	20.5	0.86	0.355	0.443	0.012	0.002	749.25	118.56	27.39
165 27A	3.7	0.25	0.243	2022	1968	693	289	20.4	1.05	0.352	0.450	0.015	0.002	698.59	110.54	26.86
165 8A	0.9	0.25	0.232	2977	2728	355	327	19.7	1.81	0.130	0.349	0.025	0.000	130.85	20.65	4.79
165 23A	0.8	0.25	0.232	2977	2728	337	330	20.3	1.58	0.124	0.356	0.022	0.000	103.36	16.30	3.78
165 26A	0.9	0.25	0.240	2977	2844	373	363	20.2	1.86	0.131	0.374	0.026	0.000	123.95	19.55	4.69
165 3A	4.2	0.25	0.232	3955	3604	808	457	20.4	2.27	0.224	0.380	0.032	0.001	434.10	68.63	15.92
165 24A	4.8	0.25	0.239	3955	3715	884	483	20.1	1.95	0.238	0.3[illegible]	0.027	0.001	483.61	76.45	18.27
165 9A	6.1	0.35	0.356	999	1082	519	167	20.0	0.36	0.509	0.538	0.005	0.006	2184.50	343.26	122.20
165 11A	4.1	0.35	0.340	999	979	475	165	20.4	0.66	0.495	0.556	0.009	0.004	1550.73	243.67	82.85
165 12A	7.5	0.35	0.338	2977	2844	1182	493	20.0	0.91	0.416	0.553	0.013	0.003	963.61	152.48	51.54
165 13A	1.1	0.35	0.336	2977	2831	639	345	20.0	3.18	0.226	0.374	0.044	0.000	140.82	22.28	7.49
165 10A	3.7	0.35	0.335	3955	3719	1102	505	20.3	1.55	0.296	0.427	0.022	0.001	373.69	58.82	19.70

Table 7

Single-Wheel Tests in Yuma Sand, 20 Percent Slip, Third Pass, Basic Test Tires

Test No.	Penetration-Resistance Gradient, G $N/cm^2/cm$	Deflection δ/h Design	Deflection δ/h Test	Wheel Load W, N Design	Wheel Load W, N Test	Pull P, N	Torque Q m-N	Slip s %	Sinkage z, cm	Pull Coefficient $\frac{P}{W}$	Torque Coefficient $\frac{Q}{r_e W}$	Sinkage Coefficient $\frac{z}{d}$	Strength-Load Ratio $\frac{G}{W}$ cm^{-3}	Sand Loading Number $\frac{Gd^3}{W}$	Sand Number $\frac{G(bd)^{3/2}}{W}$	Sand Mobility Number* $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
									4.00-7, 2-PR							
164 798A	5.3	0.15	0.141	444	408	57	27	20.1	1.04	0.141	0.373	0.029	0.013	594.16	95.56	13.47
164 824A	5.4	0.15	0.135	444	422	75	21	20.9	0.99	0.179	0.290	0.028	0.013	590.15	94.92	12.81
164 825A	3.1	0.15	0.161	444	488	62	29	19.4	1.08	0.127	0.344	0.030	0.006	293.06	47.13	7.59
164 821A	3.4	0.15	0.137	999	875	0	50	20.0	1.01	0.000	0.322	0.028	0.004	179.39	29.25	4.01
164 827A	6.0	0.25	0.236	444	413	124	24	19.9	0.83	0.301	0.349	0.024	0.014	660.31	106.44	25.12
164 808A	6.5	0.25	0.268	444	466	142	29	20.0	0.97	0.305	0.380	0.027	0.014	638.01	102.83	27.56
164 831A	8.3	0.25	[illegible]	888	786	155	43	19.9	1.07	0.198	0.327	0.030	0.011	483.04	77.97	17.78
164 820A	3.5	0.25	0.230	999	902	13	43	20.4	1.40	0.015	0.273	0.039	0.004	179.52	28.98	6.66
164 822A	4.3	0.25	0.275	999	888	44	44	20.2	1.52	0.050	0.288	0.043	0.005	224.26	36.20	8.14
164 829A	6.6	0.25	0.250	999	999	106	52	20.4	1.72	0.107	0.306	0.048	0.007	305.24	49.27	12.32
164 826A	3.9	0.25	0.233	1511	1431	-13	70	20.0	1.93	-0.009	0.281	0.054	0.004	127.31	[illegible]	4.80
164 833A	6.2	0.35	0.350	444	444	164	31	19.7	0.90	0.370	0.433	0.025	0.014	647.49	[illegible]	35.85
164 834A	5.7	0.35	0.340	666	644	182	39	19.7	0.80	0.287	0.373	0.022	0.009	407.71	64.96	22.09
165 1A	7.5	0.35	0.340	666	644	186	40	19.3	1.08	0.290	0.392	0.030	0.012	533.91	85.61	29.45
164 83C	6.4	0.35	0.344	999	937	173	48	20.2	1.40	0.185	0.313	0.039	0.007	312.21	50.21	17.27
164 832A	6.8	0.35	0.320	2022	1853	124	93	20.0	2.15	0.067	0.306	0.060	0.004	168.77	27.38	8.76
									4.00-20, 2-PR							
164 790A	1.8	0.15	0.139	999	902	199	111	20.1	0.72	0.222	0.348	0.010	0.002	702.14	40.52	5.63
164 791A	2.6	0.15	0.137	999	884	204	107	20.2	0.59	0.231	0.343	0.008	0.003	1046.84	60.41	8.28
164 793A	5.6	0.15	0.137	999	879	226	109	20.1	1.06	0.258	0.354	0.015	0.006	2270.37	131.03	17.95
164 788A	4.2	0.15	0.137	2022	1759	253	237	19.7	1.99	0.141	0.371	0.028	0.002	850.08	49.45	6.77
164 792A	3.3	0.15	0.139	2022	1817	262	243	20.2	1.02	0.144	0.376	0.014	0.002	651.69	37.91	5.27
164 794A	4.1	0.15	.134	2022	1768	284	223	20.0	1.53	0.161	0.356	0.021	0.002	837.13	48.69	6.52
164 795A	5.2	0.15	0.142	2022	1875	306	235	20.6	1.56	0.164	0.355	0.022	0.003	1000.05	58.17	8.26
165 14A	7.6	0.25	0.232	999	911	270	119	20.1	1.29	0.307	0.382	0.018	0.008	2969.50	167.81	38.93
165 15A	4.7	0.25	0.239	999	946	266	121	19.7	1.12	0.282	0.374	0.016	0.005	1766.23	100.94	24.12
165 19A	5.0	0.25	0.237	1511	1413	315	161	20.0	1.63	0.223	0.331	0.023	0.004	1270.25	72.68	17.22
165 16A	4.1	0.25	0.240	2022	1902	328	230	19.9	1.76	0.173	0.349	0.025	0.002	768.52	44.75	10.64
165 21A	8.0	0.35	0.340	999	964	368	135	19.8	1.37	0.382	0.418	0.019	0.008	2949.22	163.20	55.49
165 23A	1.2	0.35	0.365	999	1066	315	135	20.1	0.60	0.296	0.376	0.006	0.001	406.77	22.51	8.22
165 22A	8.0	0.35	0.339	1511	1444	484	195	19.9	1.67	0.335	0.402	0.024	0.006	1973.41	111.52	37.80
165 20A	5.3	0.35	0.327	2022	1853	484	225	19.9	1.77	0.261	0.364	0.025	0.003	1018.85	58.14	19.01
165 18A	1.8	0.35	0.316	2977	2746	342	314	19.7	0.00	0.125	0.333	0.000	0.001	230.64	13.26	4.19
									6.00-16, 2-PR							
164 802A	1.7	0.15	0.141	999	915	199	109	20.0	1.24	0.213	0.329	0.017	0.002	690.22	77.90	10.93
164 805A	3.8	0.15	0.140	999	911	231	111	19.9	0.98	0.254	0.349	0.014	0.004	1541.31	173.95	24.35
164 809A	4.8	0.15	0.141	999	928	271	119	20.2	1.02	0.292	0.370	0.014	0.005	1911.36	215.73	30.42
164 808A	3.9	0.15	0.136	1333	1204	288	146	20.3	1.25	0.240	0.346	0.017	0.003	1295.99	134.70	18.32
164 807A	3.1	0.15	0.139	2022	1911	306	228,	20.6	1.76	0.160	0.339	0.025	0.002	602.17	67.90	9.44
164 804A	1.9	0.15	0.139	2977	2746	199	308	19.9	0.45	0.073	0.316	0.006	0.001	254.67	28.72	3.99
164 810A	2.5	0.15	0.141	3955	3688	217	429	20.4	0.34	0.059	0.326	0.019	0.001	250.61	28.30	3.99

(Continued)

Table 7 (Concluded)

Test No.	Penetration-Resistance Gradient, G $N/cm^2/cm$	Deflection δ/h Design	Deflection δ/h Test	Wheel Load W, N Design	Wheel Load W, N Test	Pull P, N	Torque Q m-N	Slip s %	Sinkage z, cm	Pull Coefficient $\frac{P}{W}$	Torque Coefficient $\frac{Q}{r_e W}$	Sinkage Coefficient $\frac{z}{d}$	Strength-Load Ratio G/W cm^{-3}	Sand Loading Number $\frac{Gd^3}{W}$	Sand Number $\frac{G(bd)^{3/2}}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
									6.00-16, 2-PR (Continued)							
164 806A	4.1	0.25	0.260	999	1039	408	153	19.3	0.75	0.393	0.440	0.011	0.004	1450.21	164.03	42.65
164 818A	5.0	0.25	0.239	2022	1911	542	242	20.4	1.24	0.284	0.378	0.017	0.003	960.50	108.41	25.91
164 819A	0.8	0.25	0.234	2022	1875	355	209	19.1	0.20	0.190	0.326	[illegible]	0.000	165.79	18.71	4.38
164 812A	4.3	0.25	0.238	3955	3693	[illegible]	428	19.9	2.69	0.134	0.335	0.037	0.001	429.12	48.50	11.54
164 817A	2.9	0.25	0.239	3955	3711	422	429	19.4	1.93	0.114	0.334	0.027	0.001	288.34	32.59	7.79
164 803A	1.7	0.35	0.329	999	933	382	144	20.3	0.71	0.410	0.470	0.010	0.002	671.34	76.09	25.03
164 813A	5.3	0.35	0.360	999	1031	457	173	19.8	0.46	0.444	0.524	0.006	0.005	1871.27	212.10	76.36
164 814A	5.3	0.35	0.336	2022	1928	719	276	19.9	1.15	0.373	0.440	0.016	0.003	1008.85	113.86	38.26
164 815A	1.5	0.35	0.323	2977	2733	604	338	19.5	0.30	0.221	0.374	0.004	0.001	198.17	22.37	7.22
164 811A	4.3	0.35	0.333	3955	3751	804	444	19.7	2.25	0.214	0.363	0.031	0.001	429.67	48.39	16.11
									9.00-14, 2-PR							
164 778A	2.4	0.15	0.145	999	951	275	147	19.7	1.13	0.290	0.385	0.016	0.003	943.14	149.24	21.64
164 779A	1.8	0.15	0.147	999	973	[illegible]	134	20.0	0.99	0.288	0.398	0.014	0.002	665.60	105.32	15.48
164 780A	4.1	0.15	0.143	999	942	311	135	19.7	0.94	0.330	0.420	0.013	0.004	1586.73	251.08	35.90
164 786A	5.3	0.15	0.147	999	973	337	127	19.6	0.55	0.347	0.382	0.008	0.005	1996.81	315.97	46.45
164 774A	1.6	0.15	0.142	2022	1884	319	246	20.6	0.00	0.170	0.372	0.000	0.001	321.41	50.81	7.22
164 777A	2.6	0.15	0.142	2022	1888	359	241	20.3	1.44	0.191	0.364	0.020	0.001	507.71	80.26	11.40
164 782A	3.5	0.15	0.142	2022	1888	444	278	19.5	1.75	0.235	0.361	0.024	0.002	694.76	109.83	15.60
164 783A	1.5	0.15	0.141	2022	1057	342	243	19.5	0.89	0.184	0.373	0.012	0.001	298.86	47.25	6.66
164 785A	5.4	0.15	0.145	2022	1946	439	239	19.3	1.35	0.226	0.354	0.019	0.003	1037.14	163.07	23.65
164 775A	1.7	0.15	0.139	3955	3608	266	495	20.0	0.40	0.074	0.329	0.006	0.000	192.65	26.57	3.97
164 776A	2.8	0.15	0.144	3955	3737	359	451	20.0	1.87	0.096	0.338	0.026	0.001	288.32	45.10	6.49
164 781A	3.5	0.15	0.143	3955	3693	431	437	20.0	1.78	0.117	0.332	0.025	0.001	362.61	56.72	8.11
164 784A	5.2	0.15	0.144	3955	3719	484	430	19.2	2.26	0.130	0.326	0.031	0.001	540.01	84.46	12.16
164 787A	2.5	0.15	0.141	3955	3639	311	452	20.4	1.61	0.085	0.346	0.022	0.001	264.44	41.36	5.83
165 5A	3.2	0.25	0.231	666	608	302	104	20.4	0.30	0.496	0.516	0.004	0.005	1886.71	299.33	69.15
165 4A	3.5	0.25	0.239	999	946	404	149	20.0	0.56	0.427	0.470	0.008	0.004	1344.79	211.86	50.63
165 7A	6.6	0.25	0.237	999	937	453	177	20.2	0.20	0.483	0.577	0.003	0.007	2598.40	409.36	97.02
165 6A	3.9	0.25	0.228	2022	1919	626	262	20.4	1.34	0.326	0.410	0.019	0.002	752.72	119.11	27.16
165 37A	3.7	0.25	0.235	2022	1942	622	264	20.4	1.00	0.320	0.411	0.014	0.002	708.18	112.06	26.33
165 8A	0.9	0.25	0.230	2977	2693	471	333	20.3	0.56	0.175	0.360	0.008	0.000	132.58	20.92	4.81
165 25A	0.8	0.25	0.232	2977	2728	471	326	19.9	0.10	0.173	0.353	0.001	0.000	103.36	15.30	3.78
165 3A	4.2	0.25	0.232	3955	3604	724	441	19.6	2.49	0.201	0.367	0.035	0.001	434.10	68.63	15.92
165 24A	4.8	0.25	0.242	3955	3773	755	457	19.7	2.31	0.200	0.367	0.032	0.001	476.20	75.28	18.22
165 9A	6.1	0.35	0.349	999	995	475	162	19.8	0.30	0.478	0.532	0.004	0.006	2243.02	352.45	123.01
165 11A	4.1	0.35	0.334	999	959	453	165	20.0	0.56	0.472	0.551	0.008	0.004	1550.73	243.67	81.39
165 12A	7.5	0.35	0.334	2977	2817	1093	414	20.0	0.91	0.388	0.464	0.013	0.003	978.73	153.92	51.41
165 13A	1.1	0.35	0.331	2977	2786	764	354	19.7	0.30	0.274	0.388	0.004	[illegible]	143.07	22.64	7.49
165 10A	3.7	0.35	0.333	3955	3688	1035	489	20.3	1.74	0.281	0.411	0.024	0.001	376.84	59.31	19.75

Table 8

Penetration Resistance Gradient, First Pass, Basic Test Tires

Test No.	Design Deflection $\frac{\delta}{h}$	Penetration-Resistance Gradient, G $N/cm^2/cm$
4.00-7, 2-PR		
164 798A	0.15	5.3
164 824A	0.15	5.4
164 825A	0.15	3.1
164 799A	0.15	5.4
164 800A	0.15	4.2
164 801A	0.15	4.9
164 821A	0.15	3.4
164 827A	0.25	6.0
164 828A	0.25	6.5
164 8[illegible]A	0.25	8.3
164 820A	0.25	3.5
164 822A	0.25	4.3
164 829A	0.25	6.6
164 826A	0.25	3.9
164 833A	0.35	6.2
164 834A	0.35	5.7
165 1A	0.35	7.5
164 830A	0.35	6.4
165 2A	0.35	1.5
164 832A	0.35	6.8
4.00-20, 2-PR		
164 790A	0.15	1.8
164 791A	0.15	2.6
164 793A	0.15	5.6
164 788A	0.15	4.2
164 789A	0.15	2.0
164 792A	0.15	3.3
164 794A	0.15	4.1
164 795A	0.15	5.2
165 14A	0.25	7.6
165 15A	0.25	4.7
165 19A	0.25	5.0
165 16A	0.25	4.1
165 17A	0.25	0.9
165 21A	0.35	8.0
165 23A	0.35	1.2
165 22A	0.35	8.0
165 20A	0.35	5.3
165 18A	0.35	1.8
6.00-16, 2-PR		
164 802A	0.15	1.7
164 805A	0.15	3.8
164 809A	0.15	4.8
164 808A	0.15	3.9
164 807A	0.15	3.1
164 804A	0.15	1.9
6.00-16, 2-PR (Continued)		
165 35A	0.15	1.2
164 810A	0.15	2.5
164 816A	0.25	4.1
165 37A	0.25	4.6
164 818A	0.25	5.0
164 819A	0.25	0.8
165 32A	0.25	0.6
165 33A	0.25	0.7
164 812A	0.25	4.3
164 817A	0.25	2.9
165 31A	0.25	1.0
164 803A	0.35	1.7
164 813A	0.35	5.3
164 814A	0.35	5.3
164 815A	0.35	1.5
165 34A	0.35	1.0
164 811A	0.35	4.3
9.00-14, 2-PR		
164 778A	0.15	2.4
164 779A	0.15	1.8
164 780A	0.15	4.1
164 786A	0.15	5.3
164 774A	0.15	1.6
164 777A	0.15	2.6
164 782A	0.15	3.5
164 783A	0.15	1.5
164 785A	0.15	5.4
164 775A	0.15	1.7
164 776A	0.15	2.8
164 781A	0.15	3.5
164 784A	0.15	5.2
164 787A	0.15	2.5
165 5A	0.25	3.2
165 4A	0.25	3.5
165 7A	0.25	6.6
165 6A	0.25	3.9
165 27A	0.25	3.7
165 8A	0.25	0.9
165 25A	0.25	0.8
165 26A	0.25	0.7
165 28A	0.25	0.9
165 3A	0.25	4.2
165 24A	0.25	4.8
165 9A	0.35	6.1
165 11A	0.35	4.1
165 12A	0.35	7.5
165 13A	0.35	1.1
165 10A	0.35	3.7

Table 9

Sand Mobility Numbers Computed from Second- and Third-Pass Soil-Strength Data, Basic Test Tires

Test No.	Second Pass: Penetration-Resistance Gradient, G N/cm²/cm	Second Pass: Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$	Third Pass: Penetration-Resistance Gradient, G N/cm²/cm	Third Pass: Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
		4.00-7, 2-PR		
164 798A	4.3	11.06	4.5	11.40
164 824A	4.3	10.11	4.6	10.89
164 825A	2.8	6.89	3.3	7.92
164 799A	3.9	4.[illegible]	2-pass test	
164 800A	3.4	3.96	2-pass test	
164 822A	3.0	3.51	3.1	3.69
164 827A	4.9	20.04	5.3	22.26
164 828A	5.8	24.69	6.0	26.06
164 831A	5.1	13.01	6.6	14.28
164 820A	0.7	5.10	3.1	5.90
164 828A	3.4	6.36	4.5	6.62
164 829A	4.2	7.83	4.2	7.79
164 826A	3.3	3.98	3.4	4.14
164 833A	5.2	31.49	5.2	29.61
164 834A	4.7	18.37	5.0	19.46
165 1A	6.2	24.73	7.2	28.38
164 830A	4.5	11.77	5.0	11.60
165 2A	1.1	2.88	2-pass test	
164 832A	3.8	4.94	4.4	5.75
		4.00-20, 2-PR		
164 790A	1.9	6.11	2.2	6.93
164 791A	2.3	7.47	2.4	7.84
164 793A	3.7	11.67	3.7	11.82
164 786A	2.3	3.71	2.7	4.37
164 789A	1.8	2.83	2-pass test	
164 796A	2.3	3.71	2.3	3.73
164 794A	2.8	4.52	2.8	4.57
164 795A	3.0	4.78	2.8	4.56
165 14A	6.6	33.97	7.2	36.85
165 15A	3.2	15.70	3.0	15.16
165 19A	3.2	10.68	3.1	10.71
165 16A	3.1	8.16	2.7	7.10
165 17A	0.7	1.23	2-pass test	
165 21A	6.1	42.32	6.4	44.20
165 23A	1.8	11.90	2.4	16.43
165 22A	5.0	25.55	5.8	27.55
165 20A	3.1	11.20	3.0	10.73
165 18A	1.1	2.76	1.8	4.19
		6.00-16, 2-PR		
164 802A	1.5	9.89	1.9	10.38
164 805A	3.0	19.00	3.1	19.81
		6.00-16, 2-PR (Continued)		
164 806A	1.7	21.66	4.0	25.04
164 808A	2.9	[illegible]	3.1	14.70
164 807A	2.2	6.84	2.7	8.28
164 804A	1.9	4.04	2.3	4.98
164 810A	2.2	[illegible]	2.5	[illegible]
164 816A	1.8	[illegible]	3.7	18.70
165 17A	4.4	[illegible]	2-pass test	
164 818A	[illegible]	[illegible]	[illegible]	17.41
164 819A	1.6	[illegible]	[illegible]	11.72
164 812A	2.5	6.62	2.9	7.74
164 817A	[illegible]	6.66	3.0	8.01
164 803A	1.6	21.09	1.8	25.83
164 813A	1.9	55.56	[illegible]	62.97
164 814A	1.6	25.74	[illegible]	24.26
164 815A	[illegible]	11.02	2.5	12.47
164 811A	2.2	8.01	2.4	8.66
		9.00-14 2-PR (Oehrig)		
164 770A	2.1	10.58	2.2	[illegible].72
164 779A	1.8	15.56	1.9	[illegible]
164 780A	[illegible]	10.21	[illegible]	[illegible]
164 786A	[illegible]	[illegible]	4.2	10.42
164 774A	1.8	8.14	2.3	10.[illegible]
164 777A	2.0	8.58	2.2	9.84
164 782A	[illegible]	11.40	2.8	12.24
164 783A	1.9	7.85	[illegible]	9.93
164 785A	1.7	16.35	4.3	18.02
164 775A	2.1	4.87	2.4	5.67
164 776A	2.1	4.01	2.6	[illegible]
164 781A	[illegible]	[illegible]	2.7	[illegible]
164 784A	[illegible]	7.64	[illegible]	[illegible]
164 787A	2.1	[illegible]	2.6	6.02
165 5A	4.0	64.17	3.2	69.15
165 4A	[illegible]	47.16	[illegible]	[illegible]
165 7A	6.1	88.55	6.5	94.25
165 6A	1.4	21.61	4.1	28.47
165 27A	[illegible]	22.97	[illegible]	25.19
165 8A	1.6	8.21	2.4	11.00
165 25A	1.6	8.10	2.8	10.80
165 28A	1.5	7.47	2-pass test	
165 3A	2.8	10.48	[illegible]	12.33
165 24A	1.8	14.47	3.9	14.53
164 9A	6.0	219.49	5.8	117.54
165 11A	[illegible]	78.43	[illegible]	78.67
165 12A	6.1	[illegible].48	6.5	[illegible]
165 13A	1.6	11.21	2.[illegible]	15.92
165 10A	2.6	13.56	2.7	14.31

(Continued)

Table 10

4x4 Vehicle Tests in Yuma Sand, Laboratory Tests, 20 Percent Slip, First Pass

Test No.	Penetration-Resistance Gradient, G $N/cm^2/cm$	Design Deflection $\frac{\delta}{h}$	Design Load W, N	Pull P, N	Pull Coefficient $\frac{P}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
			4.50-18, 4-PR			
32 4	4.7	0.15	3956	489	0.031	4.3
33 4	3.8	0.15	3956	-267	-0.017	3.[illegible]
36 4	3.5	0.15	3956	-400	-0.025	3.2
38 4	5.9	0.15	3956	578	0.037	5.4
34 4	3.7	0.35	3956	2267	0.143	7.9
37 4	3.1	0.35	3956	1778	0.112	6.7
40 4	5.1	0.35	3956	3467	0.219	10.9
41 4	3.9	0.35	3956	2711	0.171	8.3
			9.00-14, 2-PR			
46 4	5.3	0.15	3956	3200	0.202	11.7
47 4	3.0	0.15	3956	1000	0.063	6.6
48 4	3.4	0.15	3956	2178	0.138	7.6
49 4	1.8	0.15	3956	289	0.018	4.0
43 4	3.4	0.35	3956	5200	0.329	17.7
44 4	2.6	0.35	3956	4000	0.253	13.5
45 4	5.2	0.35	3956	5733	0.362	26.4
51 4	1.7	0.35	3956	3222	0.204	8.7

Table [illegible]

Vehicle Tests in Coarse-Grained Soil, Field Tests,
Maximum Drawbar Pull, First Pass

Test No.	Cone Index* 0-6 in.	[illegible]	Wheel Load W (lb)	Inflation Pressure lb/in.^{2}	Deflection [illegible]	$\frac{P}{W}$**	Sand Mobility Number $\frac{(Cbd)^{3/2}}{W} \times \frac{\delta}{h}$
			M38A1, 4x4 (Jeep), Padre Island, Tex.				
[illegible]	[illegible]	[illegible]	[illegible],99[illegible]	[illegible]	0.086	0.243	49.4
[illegible]	[illegible]	[illegible]	[illegible],99[illegible]	[illegible]	0.113	0.320	[illegible]
[illegible]	[illegible]	[illegible]	[illegible],991	[illegible]	0.134	[illegible]	73.5
[illegible]	[illegible]	[illegible]	[illegible] 99[illegible]	[illegible]	0.173	[illegible]	81.0
[illegible]	[illegible]	[illegible]	[illegible],259	[illegible]	0.100	[illegible]	48.2
[illegible]	362	35	[illegible]	[illegible]	0.120	0.295	[illegible]
[illegible]	352	[illegible]	3,259	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	3,259	[illegible]	[illegible]	[illegible]	90.8
29	290	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.130	[illegible]	46.3
[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			M37, 4x4 Truck, 3/4-Ton, Padre Island, Tex.				
[illegible]	367	[illegible]	6,311	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	347	[illegible]	[illegible]	[illegible]	[illegible]	0.255	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.297	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.369	[illegible]
[illegible]	312	28	[illegible]	[illegible]	0.120	[illegible]	[illegible]
[illegible]	[illegible]	30	[illegible]	14	0.156	0.227	[illegible]
[illegible]	330	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	340	31	[illegible]	7	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	25	7,978	21	[illegible]	[illegible]	[illegible]
73	[illegible]	[illegible]	7,978	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	360	33	7,978	[illegible]	[illegible]	[illegible]	[illegible]
79	[illegible]	[illegible]	[illegible]	21	[illegible]	[illegible]	[illegible]
[illegible]	96	9	[illegible]	21	[illegible]	[illegible]	13.0
[illegible]	337	30	7,978	14	[illegible]	0.253	62.1
[illegible]	62	6	7,978	14	0.180	[illegible]	[illegible]
[illegible]	122	11	7,978	14	[illegible]	[illegible]	22.7
[illegible]	300	27	7,978	10	0.216	[illegible]	[illegible]
93	69	6	7,978	10	0.216	0.171	[illegible]
94	110	10	7,978	10	0.216	0.240	24.6
97	330	30	[illegible]	7	0.276	[illegible]	93.5
101	98	9	7,978	7	0.276	[illegible]	[illegible]
102	101	9	7,978	7	[illegible]	[illegible]	[illegible]
			M37, 4x4 Truck, 3/4-Ton, Cape Cod, Mass.				
103	123	12	6,311	21	[illegible]	0.161	17.2
104	128	12	6,311	21	0.114	0.157	17.2
105	104	9	6,311	14	0.144	0.177	17.7
106	136	12	6,311	14	0.144	0.212	22.7
107	139	12	6,311	14	0.144	0.200	23.2
108	138	12	6,311	10	0.168	0.250	27.1
109	131	12	6,311	10	0.168	0.239	[illegible]
110	131	12	6,311	10	0.168	0.250	25.9
111	120	11	6,311	7	0.198	0.306	27.8
112	125	11	6,311	7	0.198	0.288	29.2
113	103	9	6,311	7	0.198	0.299	23.6
			M135, 6x6 Truck, 2-1/2-Ton, Padre Island, Tex.				
147	325	29	12,933	21	0.125	0.284	46.8
148	105	9	12,933	21	0.125	0.133	15.2
150	352	32	12,933	14	0.195	0.342	78.4
153	352	32	12,933	10	0.220	0.372	88.4
156	317	29	12,933	7	0.270	0.419	98.4
159	144	13	13,689	41	0.090	0.072	14.0
160	114	10	13,689	41	0.090	0.061	11.1
163	143	13	13,689	21	0.160	0.180	24.9
164	160	14	13,689	21	0.160	0.200	27.5
165	156	14	13,689	21	0.160	0.192	27.0
166	129	12	13,689	21	0.160	0.147	22.3
167	139	12	13,689	14	0.210	0.220	31.[illegible]

(Continued)

* Values taken directly from TR 3-240, 17th Supplement.

** $\frac{P}{W}$ represents the ratio of the total pull to vehicle weight.

(1 of 4 Sheets)

Table 11 (Continued)

Test No.	Cone Index 0-15 cm	Penetration Resistance Gradient G $N/cm^2/cm$	Wheel Load W (N)	Inflation Pressure N/cm^2	Deflection δ/h	$\frac{P}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
			M135, 6x6 Truck, 2-1/2-Ton, Padre Island, Tex. (Continued)				
168	[illegible]	14	13,689	[illegible]	0.210	0.226	34.5
169	125	11	13,689	14	0.210	0.207	28.5
170	142	13	13,689	14	0.210	0.216	32.7
171	125	12	13,689	10	0.265	0.255	38.7
172	155	14	13,689	10	0.265	0.275	44.7
173	130	12	13,689	10	0.265	0.261	37.0
174	134	12	13,689	10	0.265	0.252	38.7
175	140	13	13,689	10	0.265	0.265	40.4
176	134	12	13,689	7	0.360	0.317	48.2
177	132	12	13,689	7	0.360	0.318	47.1
			M34, 6x6 Truck, 2-1/2-Ton, Suscinio, France				
178	78	7	8,533	14	0.132	0.159	17.5
179	92	8	8,533	14	0.132	0.154	20.9
180	51	5	8,533	10	0.147	0.157	12.8
181	70	6	8,533	10	0.147	0.151	17.2
182	92	8	8,533	10	0.147	0.144	23.3
183	94	8	8,533	7	0.176	0.220	27.9
184	[illegible]	6	8,533	7	0.176	0.219	18.9
185	55	5	8,533	7	0.176	0.197	16.2
			M34, 6x6 Truck, 2-1/2-Ton, Portaile, France				
186	66	6	12,444	7	0.250	0.255	19.6
187	125	11	12,444	7	0.250	0.283	37.5
			DUKW 353, 6x6 Truck, 2-1/2-Ton, La Turballe, France				
188	103	9	10,889	10	0.203	0.249	26.8
189	141	[illegible]	10,889	10	0.203	0.293	37.0
190	86	8	10,889	7	0.252	0.316	26.3
			DUKW 353, 6x6 Truck, 2-1/2-Ton, Suscinio, France				
191	143	13	14,578	21	0.171	0.215	23.8
192	133	12	14,578	21	0.171	0.159	21.8
193	105	9	14,578	21	0.171	0.190	17.3
194	106	9	14,578	21	0.171	0.194	17.3
195	133	12	14,578	21	0.171	0.194	21.8
196	140	13	14,578	21	0.171	0.202	23.2
197	107	10	14,578	14	0.225	0.263	23.5
198	67	6	14,578	14	0.225	0.193	14.3
199	95	9	14,578	14	0.225	0.216	20.9
200	67	6	14,578	14	0.225	0.238	14.3
201	97	8	14,578	14	0.225	0.188	21.1
202	104	[illegible]	14,578	14	0.225	0.191	22.8
			DUKW 353, 6x6 Truck, 2-1/2-Ton, La Turballe, France				
203	80	7	14,578	14	0.225	0.212	17.6
204	143	13	14,578	14	0.225	0.195	31.3
			DUKW 353, 6x6 Truck, 2-1/2-Ton, Suscinio, France				
205	68	6	14,578	10	0.277	0.193	15.7
206	61	5	14,578	10	0.277	0.200	16.0
207	63	6	14,578	10	0.277	0.230	18.4
208	69	6	14,578	10	0.277	0.234	18.4
			DUKW 353, 6x6 Truck, 2-1/2-Ton, La Turballe, France				
209	95	9	14,578	10	0.277	0.289	25.7
210	96	9	14,578	10	0.277	0.261	25.7
211	86	8	14,578	10	0.277	0.262	23.2
212	78	7	14,578	7	0.348	0.305	20.8
213	117	11	14,578	7	0.348	0.328	31.3
214	86	8	14,578	7	0.348	0.322	23.2
			DUKW 353, 6x6 Truck, 2-1/2-Ton, Cape Cod, Mass.				
221	183	17	11,333	14	0.176	0.244	40.3
222	159	14	11,333	14	0.176	0.227	34.7
223	172	15	11,333	14	0.176	0.262	37.3
224	50	5	11,333	14	0.176	0.078	11.1
225	49	5	11,333	14	0.176	0.093	11.0
226	60	5	11,333	14	0.176	0.090	13.3
227	172	15	11,333	10	0.216	0.317	45.0

(Continued)

Table 11 (Continued)

Test No.	Cone Index 0-15 cm	Penetration-Resistance Gradient G N/cm^2/cm	Wheel Load W (N)	Inflation Pressure N/cm^2	Deflection δ/h	$\frac{P}{W}$	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h}$
			DUKW 353, 6x6 Truck, 2-1/2-Ton, Cape Cod, Mass. (Continued)				
228	162	17	11,333	10	0.216	0.277	48.5
229	142	13	11,333	10	0.216	0.293	38.1
230	46	-	11,333	10	0.216	0.118	12.1
231	43	-	11,333	10	0.216	0.105	11.3
232	40	4	11,333	10	0.216	0.108	10.6
233	162	15	11,333	7	0.262	0.370	[illegible]
234	160	14	11,333	7	0.262	0.337	52.2
235	129	12	11,333	7	0.262	0.340	42.0
236	40	4	11,333	7	0.262	0.214	13.4
237	39	4	11,333	7	0.262	0.213	13.0
238	44	4	11,333	7	0.262	0.191	14.7
			M41, 6x6 Truck, 5-Ton, Vicksburg, Miss., Miss. River Sandbar				
240	97	9	17,155	21	0.172	0.169	28.5
241	76	7	17,155	21	0.172	0.165	22.3
242	340	31	17,155	21	0.172	0.330	100.0
248	305	28	17,155	14	0.153	0.397	96.5
251	99	9	17,155	10	0.258	0.283	44.1
253	360	33	17,155	10	0.258	0.441	161.0
258	360	33	17,155	7	0.316	0.479	197.0
			Bucket Loader, 4x4 Tractor, Vicksburg, Miss., Miss. River Sandbar				
285	122	11	15,111	21	0.104	0.201	25.8
286	128	12	15,111	21	0.104	0.203	27.1
287	125	11	15,111	21	0.104	0.202	26.6
288	112	10	15,111	21	0.104	0.192	23.7
289	125	11	15,111	14	0.141	0.252	36.0
290	120	11	15,111	14	0.141	0.238	34.3
291	124	11	15,111	10	0.173	0.300	42.8
292	121	11	15,111	10	0.173	0.303	41.9
293	117	11	15,111	10	0.173	0.289	41.0
294	109	10	15,111	7	0.233	0.340	51.0
295	123	11	15,111	7	0.233	0.355	58.2
			Tournadozer, 4x4 Tractor, Vicksburg, Miss., Miss. River Sandbar				
296	103	9	34,489	21	0.178	0.216	42.3
297	130	12	34,489	21	0.178	0.213	53.4
298	115	10	34,489	21	0.178	0.215	47.6
299	147	13	34,489	21	0.178	0.235	60.7
300	141	13	34,489	21	0.178	0.216	58.0
301	136	12	34,489	14	0.208	0.283	66.0
302	138	12	34,489	14	0.208	0.272	66.7
303	136	12	34,489	14	0.208	0.302	66.0
304	136	12	34,489	14	0.208	0.281	66.0
305	122	11	34,489	14	0.208	0.287	58.4
306	136	12	34,489	14	0.208	0.281	66.0
307	138	12	34,489	14	0.208	0.272	66.7
308	125	11	34,489	10	0.250	0.325	73.8
309	[illegible]	11	34,489	10	0.250	0.327	[illegible]
310	139	12	34,489	10	0.250	0.339	81.5
311	135	12	34,489	10	0.250	0.327	[illegible]
312	130	12	34,489	10	0.250	0.316	[illegible]
313	124	11	34,489	10	0.250	0.338	[illegible]
314	134	12	34,489	10	0.250	0.332	[illegible]
315	133	12	34,489	10	0.250	0.338	[illegible]
316	116	11	34,489	7	0.272	0.397	[illegible]
317	137	12	34,489	7	0.272	0.402	87.5
318	116	11	34,489	7	0.272	0.389	[illegible]
319	138	12	34,489	7	0.272	0.412	88.5
320	133	12	34,489	7	0.272	0.399	87.5
			GOER, 4x4 Cargo Carrier, 5-Ton ([illegible]), Vicksburg, Miss., Miss. River Sandbar				
321	143	13	29,644	21	0.172	0.278	48.8
322	113	10	29,644	21	0.172	0.254	36.8
323	119	11	29,644	21	0.172	0.241	40.6
324	132	12	29,644	21	0.172	0.274	45.2
325	140	13	29,644	21	0.172	0.261	47.8
326	143	13	29,644	21	0.172	0.267	48.5
327	126	11	29,644	21	0.172	0.268	43.4
328	151	14	29,644	14	0.215	0.335	65.2
329	151	14	29,644	14	0.215	0.345	65.2
330	136	12	29,644	14	0.215	0.305	59.1
331	126	11	29,644	14	0.215	0.320	54.2
332	134	12	29,644	14	0.215	0.327	57.9
333	135	12	29,644	14	0.215	0.325	58.5

(Continued)

Table 11 (Concluded)

Test No.	Cone Index 0-15 cm	Penetration-Resistance Gradient G N/cm², cm	Wheel Load N (W)	Inflation Pressure N/cm²	Deflection δ/h	P/W	Sand Mobility Number $\frac{G(bd)^{3/2}}{W} \cdot \frac{\delta}{h}$
			GOER, 4x4 Cargo Carrier, 5-Ton (18-26), Vicksburg, Miss., Miss. River Sandbar (Continued)				
334	157	14	29,644	14	0.215	0.380	67.6
335	146	13	29,644	10	0.247	0.368	71.9
336	136	12	29,644	10	0.247	0.400	66.9
337	142	13	29,644	10	0.247	0.37[illegible]	69.7
338	147	13	29,644	10	0.247	0.366	73.9
339	144	13	29,644	10	0.247	0.306	70.[illegible]
340	136	11	29,644	7	0.294	0.431	74.2
341	145	13	29,644	7	0.294	0.447	85.[illegible]
342	141	13	29,644	7	0.294	0.444	83.2
343	149	14	29,644	7	0.294	0.428	87.4
			GOER, 4x4 Cargo Carrier, 5-Ton (15-34), Vicksburg, Miss., Miss. River Sandbar				
344	135	12	29,644	21	0.217	0.240	[illegible]
345	132	12	29,644	21	0.217	0.250	59.0
346	144	13	29,644	21	0.217	0.241	59.6
347	142	13	29,644	21	0.217	0.248	63.8
348	144	13	29,644	21	0.217	0.235	62.6
349	130	12	29,644	21	0.217	0.259	63.8
350	136	12	29,644	14	0.242	0.312	63.3
351	130	12	29,644	14	0.242	0.309	65.3
352	130	12	29,644	14	0.242	0.311	63.3
353	123	11	29,644	14	0.242	0.308	60.1
354	130	12	29,644	14	0.242	0.306	63.3
355	130	12	29,644	14	0.242	0.300	63.3
356	129	12	29,644	14	0.242	0.303	62.6
357	145	13	29,644	14	0.242	0.356	70.9
358	143	13	29,644	10	0.296	0.356	86.4
359	134	12	39,644	10	0.296	0.314	81.2
360	148	13	29,644	10	0.296	0.359	89.8
361	141	12	29,644	10	0.296	0.350	[illegible]
362	151	12	29,644	10	0.296	0.337	85.5
363	136	12	29,644	10	0.296	0.349	82.1
364	139	12	29,644	10	0.296	0.348	83.[illegible]
365	151	14	29,644	[illegible]	0.428	0.427	[illegible]
366	146	13	29,644	7	0.428	0.429	127.3
367	139	12	29,644	[illegible]	0.428	0.409	121.2
368	129	12	29,644	7	0.428	0.411	112.5
369	125	11	29,644	7	0.428	0.390	112.[illegible]

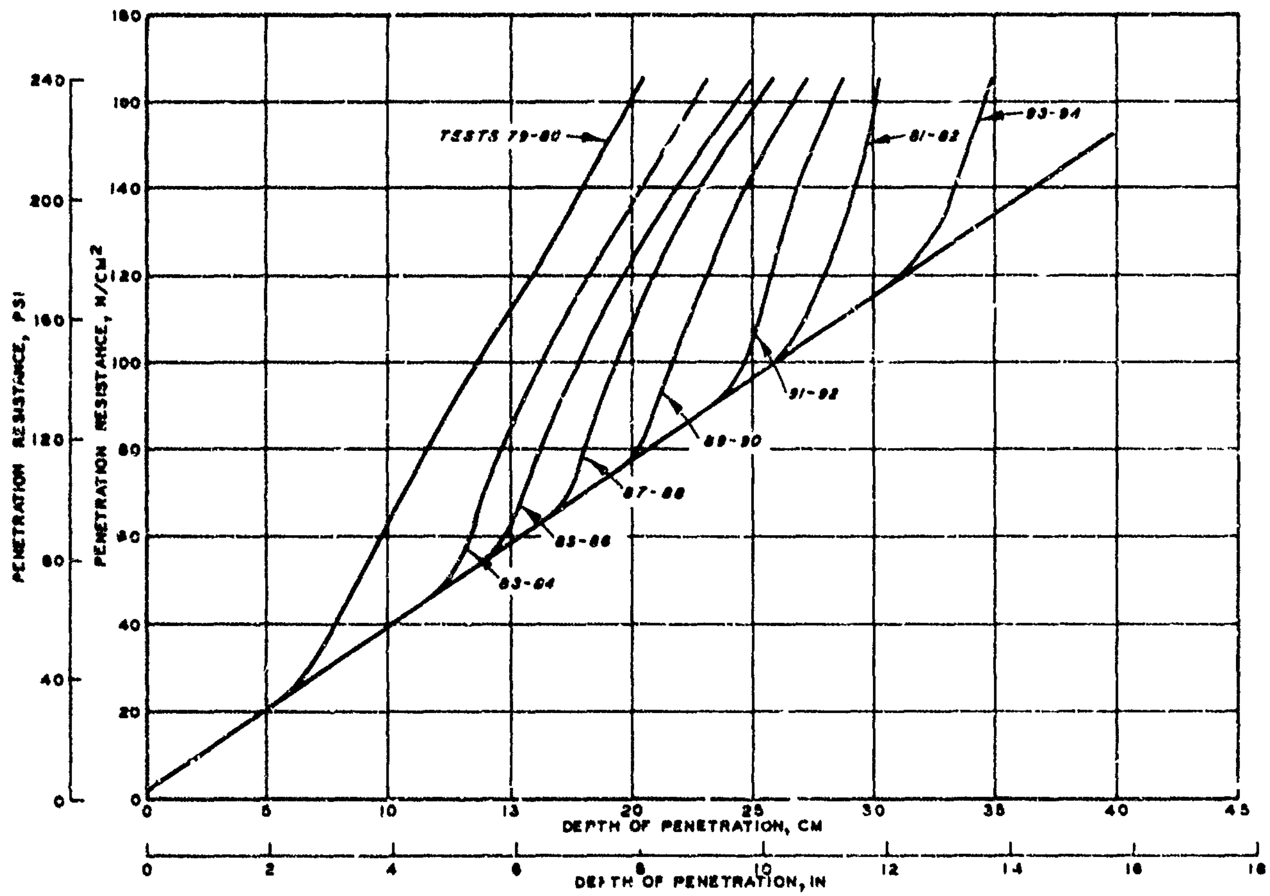
Table [illegible]

[illegible] Tests in Coarse-Grained Soils, Field Tests, [illegible] First Pass

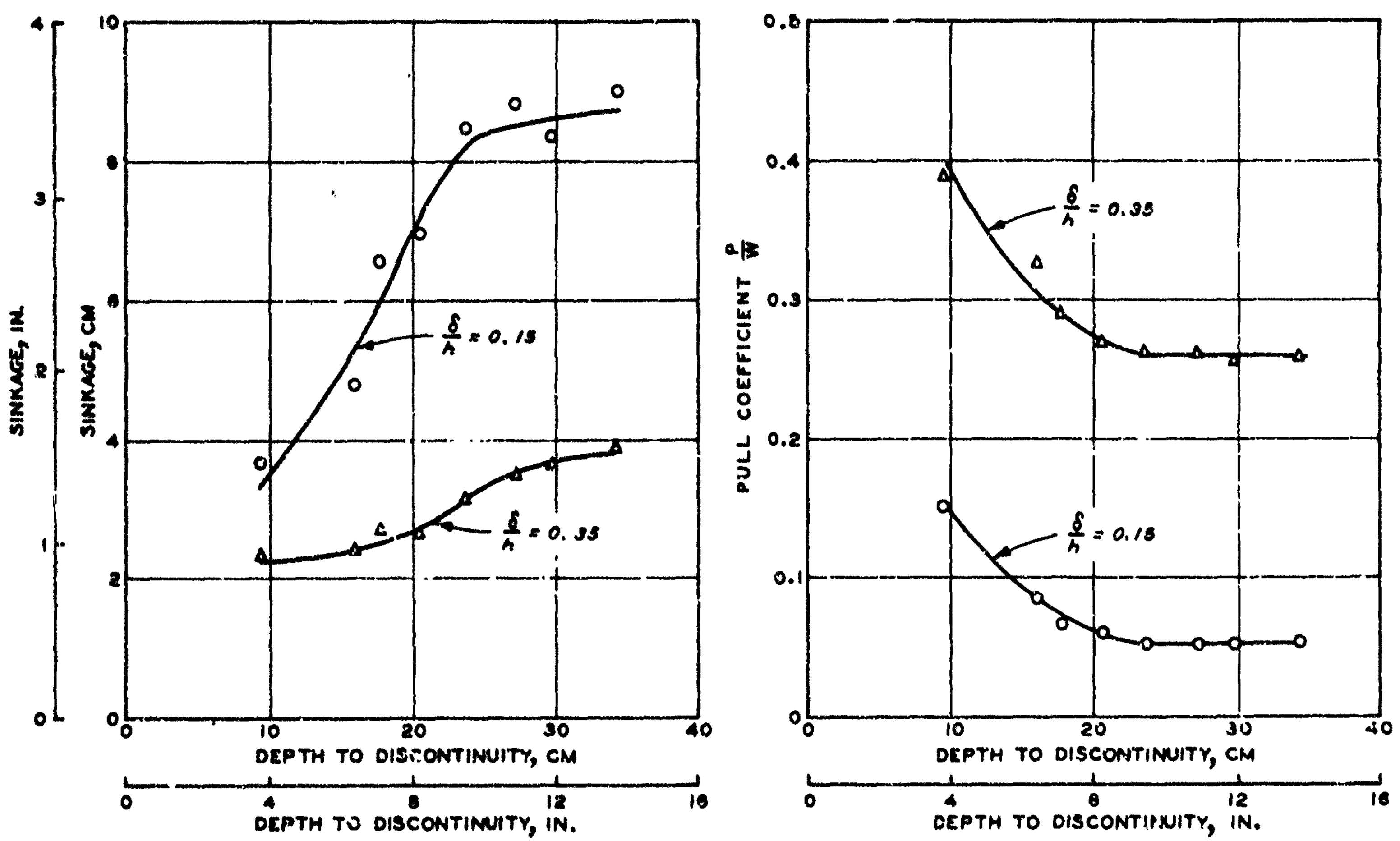
Test No.	Cone Index* CI, [illegible]	Penetration Resistance Gradient* G, [illegible]	Wheel Load N W	Inflation Pressure N/cm^2	Deflection δ/h	$\frac{P_T}{W}$**	Land Mobility Number $\frac{(Cbd)^{3/2}}{W}\cdot\frac{\delta}{h}$
			M37, 4x4 Truck, 3/4-Ton, Padre Island, Tex.				
1	330	30	7,955	21	[illegible]	0.020	44.3
2	359	33	7,955	14	[illegible]	[illegible]	66.9
3	372	34	[illegible]	10	[illegible]	0.023	22.6
4	309	28	[illegible]	7	[illegible]	[illegible]	26.3
5	141	13	7,955	21	[illegible]	0.125	19.2
6	170	15	7,955	14	[illegible]	0.076	31.6
7	174	15	[illegible]	10	[illegible]	0.043	35.6
8	164	15	[illegible]	7	[illegible]	0.051	46.7
			M35, 6x6 Truck, 2-1/2-Ton, Padre Island, Tex.				
9	82	7	10,933	21	0.120	0.164	13.2
10	128	12	10,933	14	0.166	0.086	29.0
11	109	10	10,933	10	0.185	[illegible]	38.0
12	75	7	10,933	7	0.250	0.061	[illegible]
13	124	11	13,555	21	0.130	0.142	[illegible]
14	32	3	13,555	14	0.200	0.161	7.1
15	33	3	13,555	10	0.250	0.135	9.5
16	31	3	13,555	7	[illegible]	0.148	[illegible]
			M135, 6x6 Truck, 2-1/2 Ton, Vicksburg, Miss., Miss. River Sandbar				
17	121	12	13,555	21	0.130	0.090	17.3
18	126	12	[illegible]	7	0.300	0.091	[illegible]
			M135, Tested as 4x4, Vicksburg, Miss., Miss. River Sandbar				
19	127	11	19,555	21	0.232	0.093	[illegible]
20	100	9	19,555	14	0.295	0.091	21.1
21	112	10	19,555	10	0.348	0.082	29.2
22	85	8	19,555	21	0.224	0.073	14.4
23	103	9	19,555	14	0.295	0.068	22.7
24	102	9	19,555	10	0.348	0.054	26.6
			[illegible] 353, 6x6 Truck, 2-1/2-Ton, Cape Cod, Mass.				
25	137	12	11,333	21	0.125	0.132	21.4
26	112	10	11,333	14	0.176	0.096	24.2
27	114	10	11,333	10	0.216	0.083	[illegible]
28	98	8	11,333	7	0.252	[illegible]	28.3
			M41, 6x6 Truck, 2-1/2-Ton, Padre Island, Tex.				
29	41	4	17,155	21	0.144	0.203	8.4
30	25	2	17,155	14	0.194	0.160	8.3
31	23	2	17,155	10	0.234	0.119	9.3
32	30	3	17,155	7	0.316	0.125	16.4
33	70	6	21,244	21	0.172	0.145	[illegible]
34	196	17	21,244	14	0.210	0.060	54.3
35	[illegible]	27	21,244	10	0.300	0.025	126.8
36	166	15	21,244	7	0.375	0.055	[illegible]
			Pocket Loader, 4x4 Tractor, Vicksburg, Miss., Miss. River Sandbar				
48	135	12	15,111	21	0.104	0.059	28.3
49	117	11	15,111	14	0.141	0.051	24.7
50	117	11	15,111	10	0.173	0.060	30.3
51	111	10	15,111	7	0.283	0.078	52.2
			Tournadozer, 4x4 Tractor, Vicksburg, Miss., Miss. River Sandbar				
52	28	12	34,489	21	0.178	0.085	53.4
53	[illegible]	12	34,489	14	0.208	0.069	[illegible]
54	[illegible]	12	34,489	10	0.250	0.072	[illegible]
55	126	12	34,489	7	0.272	0.055	79.8
			GOER, 4x4 Cargo Carrier, 8-Ton (18-26), Vicksburg, Miss., Miss. River Sandbar				
56	125	11	29,644	21	0.172	0.065	43.1
57	[illegible]	12	[illegible]	14	0.215	0.056	57.7
58	[illegible]	13	29,644	10	0.247	0.052	70.7
59	--	--	--	7	--	--	--
			GOER, 4x4 Cargo Carrier, 5-Ton (15-34), Vicksburg, Miss., Miss. River Sandbar				
60	[illegible]	13	29,644	21	0.217	0.056	63.4
61	[illegible]	12	29,644	14	0.242	0.059	63.3
62	130	12	29,644	10	0.296	0.05	82.8
63	--	--	--	7	--	--	--

* Values taken directly from TR 3-240, 17th Supplement.

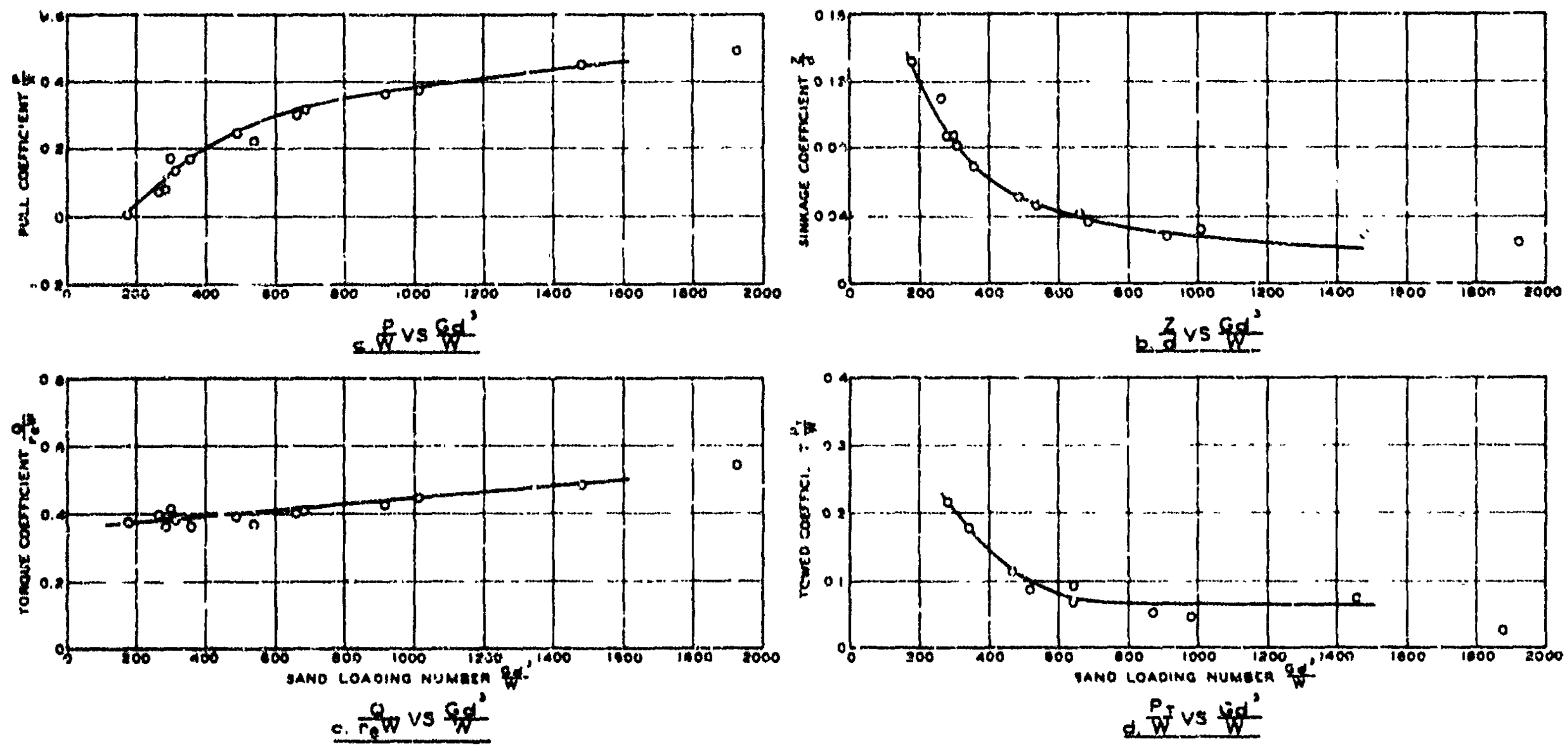
** $\frac{P_T}{W}$ represents the ratio of the total pull to vehicle weight.



PENETRATION-RESISTANCE CURVES

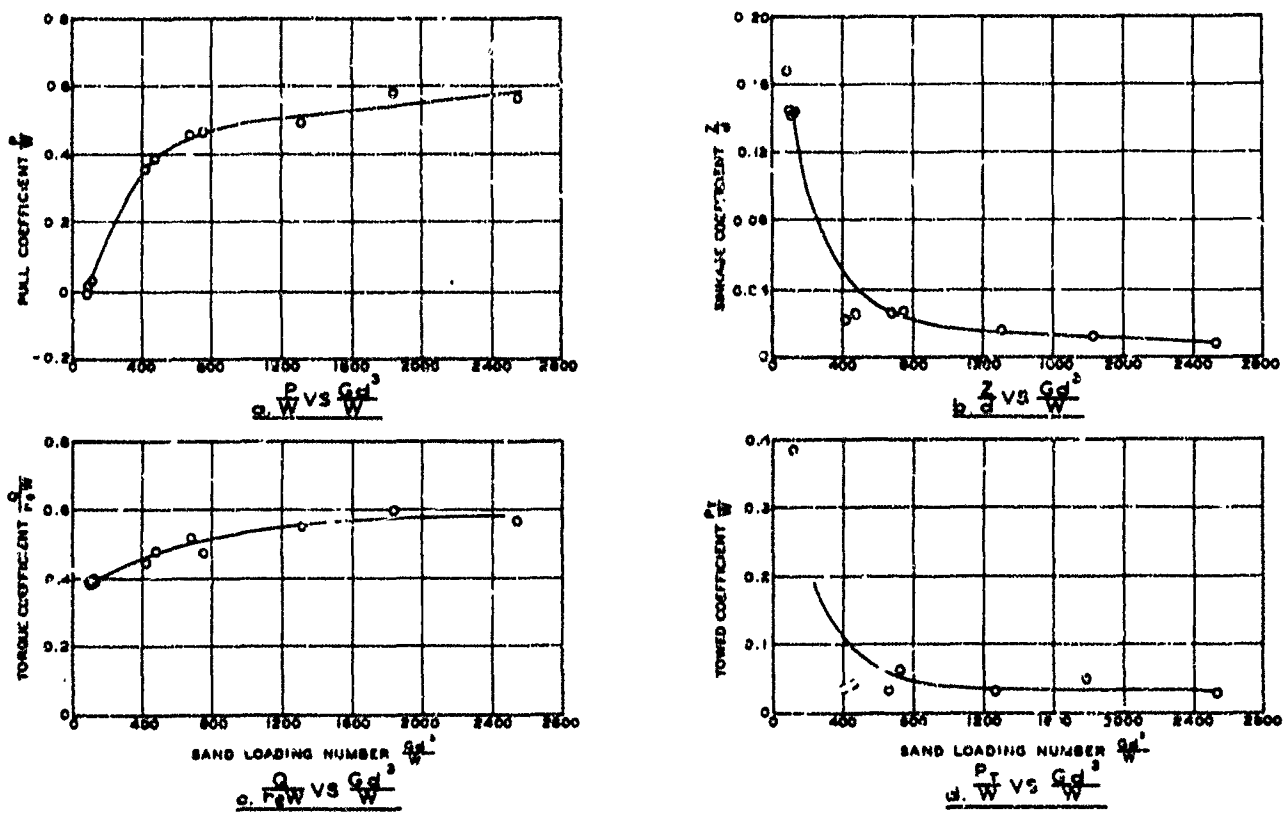


EFFECT OF SOIL STRENGTH
IN LAYERED SOIL



EFFECT OF SOIL STRENGTH ON PERFORMANCE

15% DEFLECTION
9.00-14, 2-PR TIRE
1000- TO 3950-N LOAD
G=1.5 TO 5.4



EFFECT OF SOIL STRENGTH ON PERFORMANCE

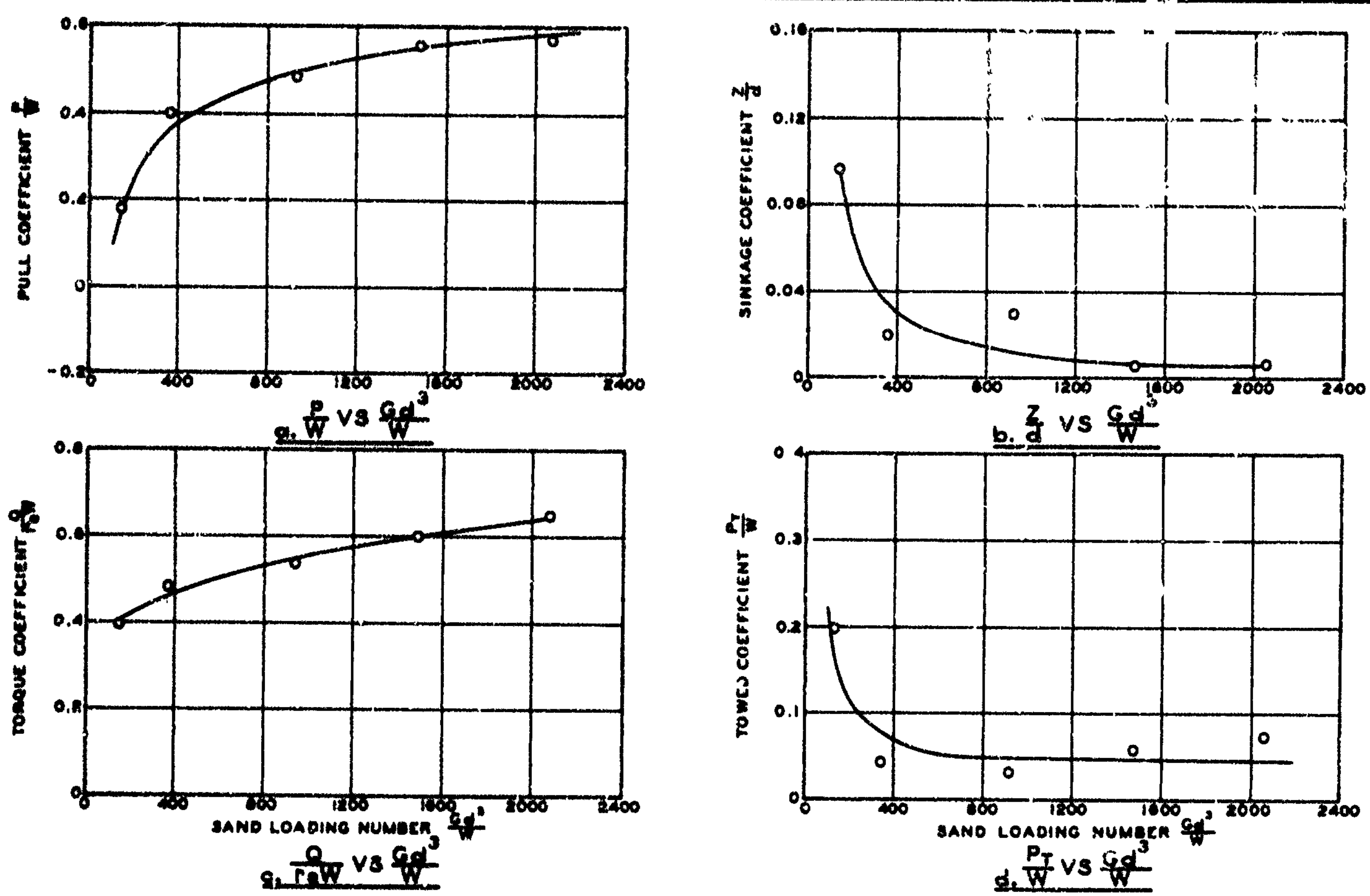
25% DEFLECTION

9.00-14, 2-PR TIRE

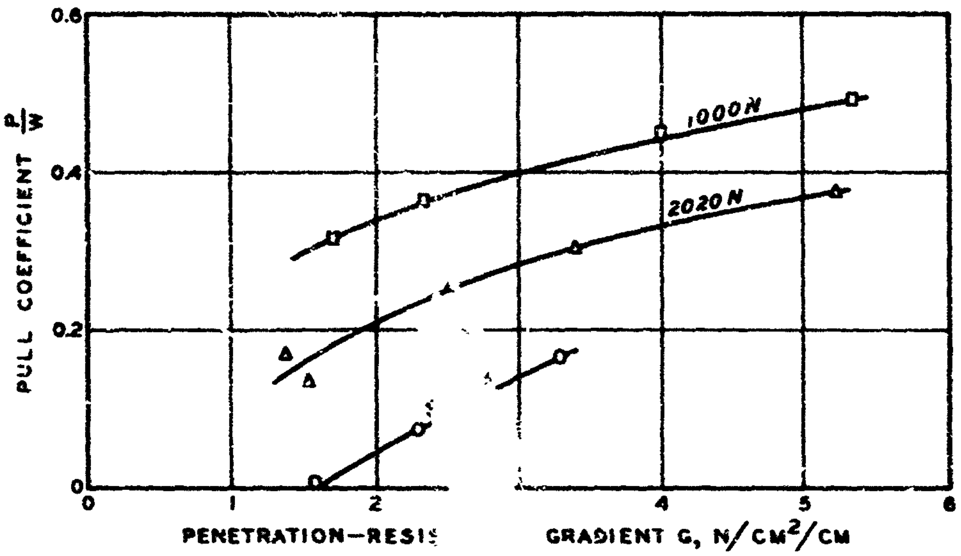
1000- TO 3950-N LOAD

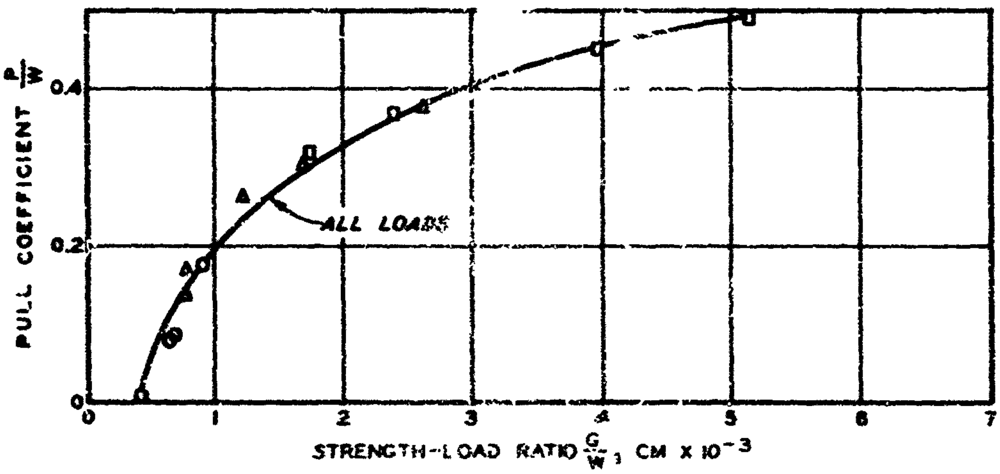
G=0.7 TO 6.6

PLATE 4



EFFECT OF SOIL STRENGTH
ON PERFORMANCE
35% DEFLECTION
9.00-14, 2-PR TIRE, 1000- TO 3950-N LOAD
G = 1.1 TO 6.1





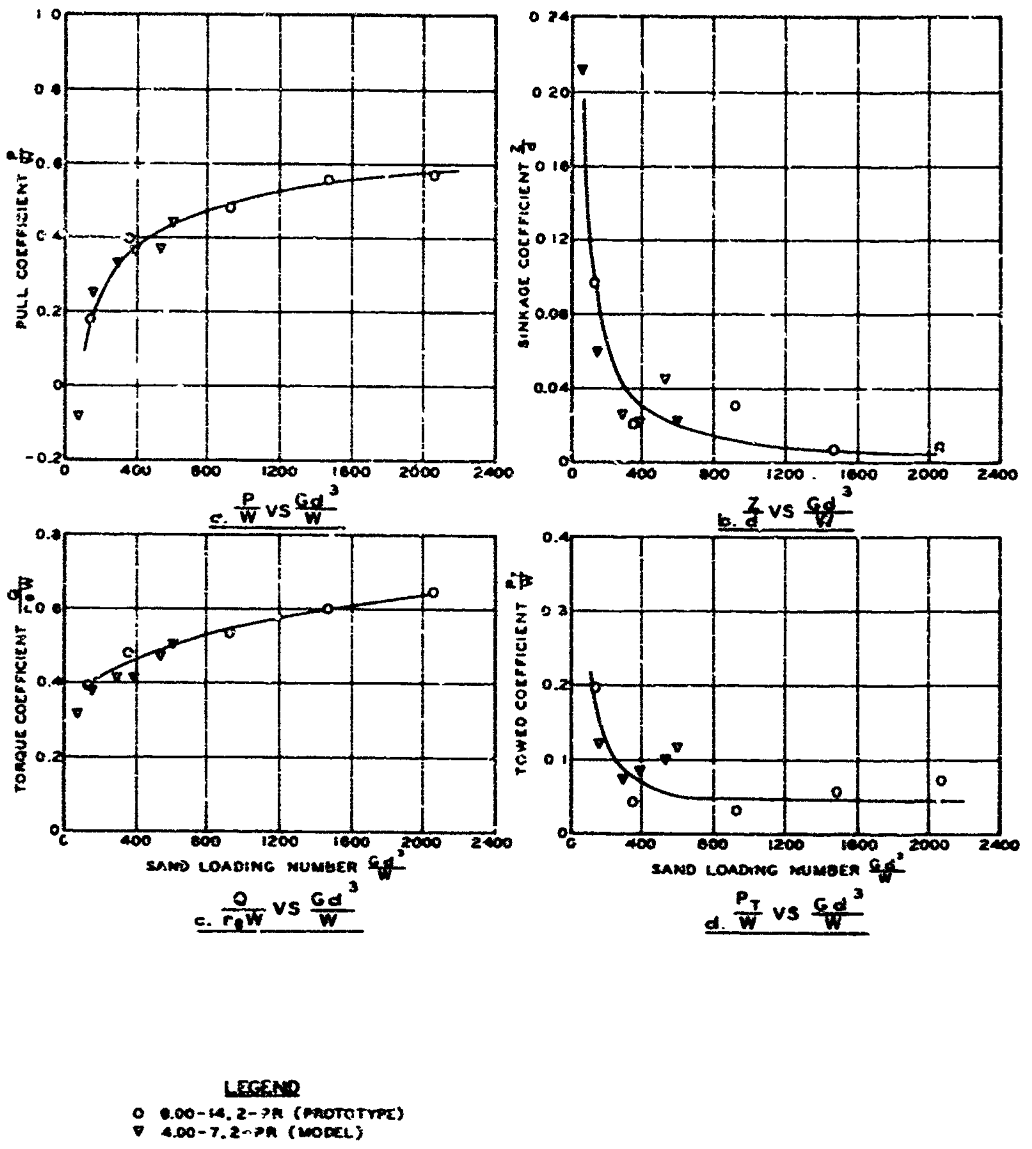
b.

LEGEND
□ 1000 N
Δ 2020 N
O 3950 N

EFFECT OF LOAD ON PERFORMANCE

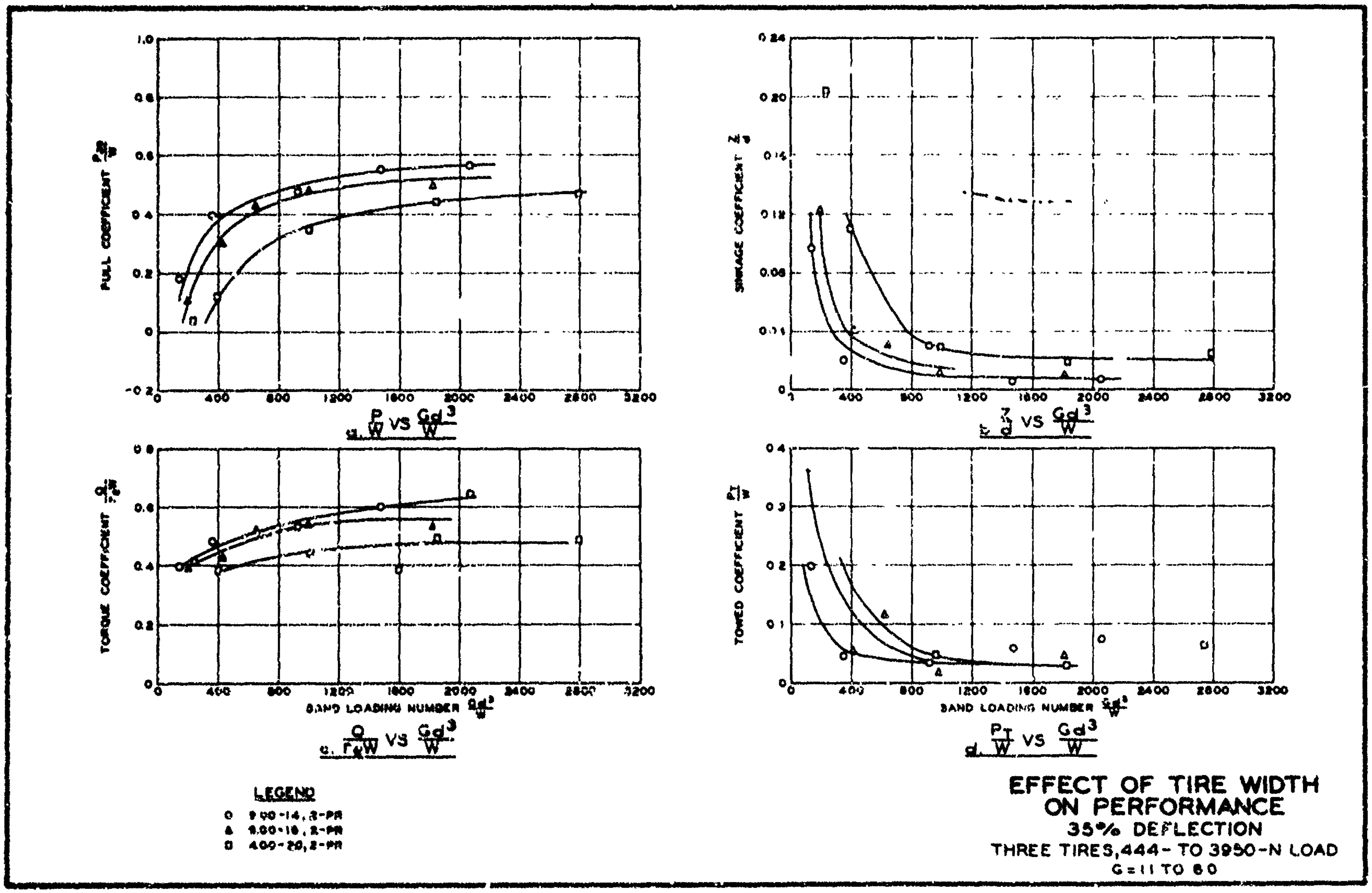
9.00-14, 2-PR TIRE
15% DEFLECTION
G= 1.5 TO 5.4

PLATE 6



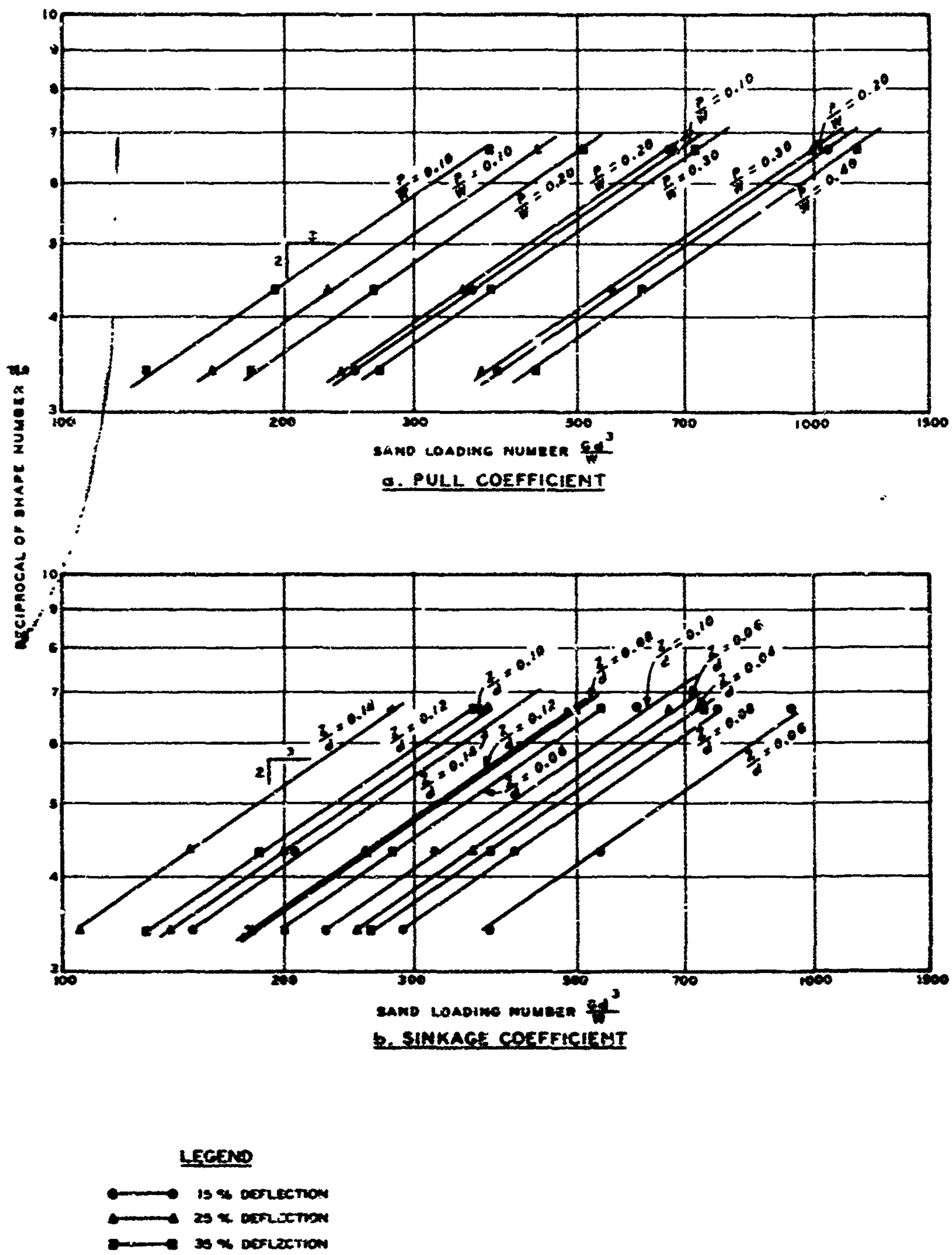
MODEL-PROTOTYPE RELATIONS

9.00-14, 2-PR AND 4.00-7, 2-PR TIRES
35% DEFLECTION
444- TO 3950-N LOAD
G=1.1 TO 6.3

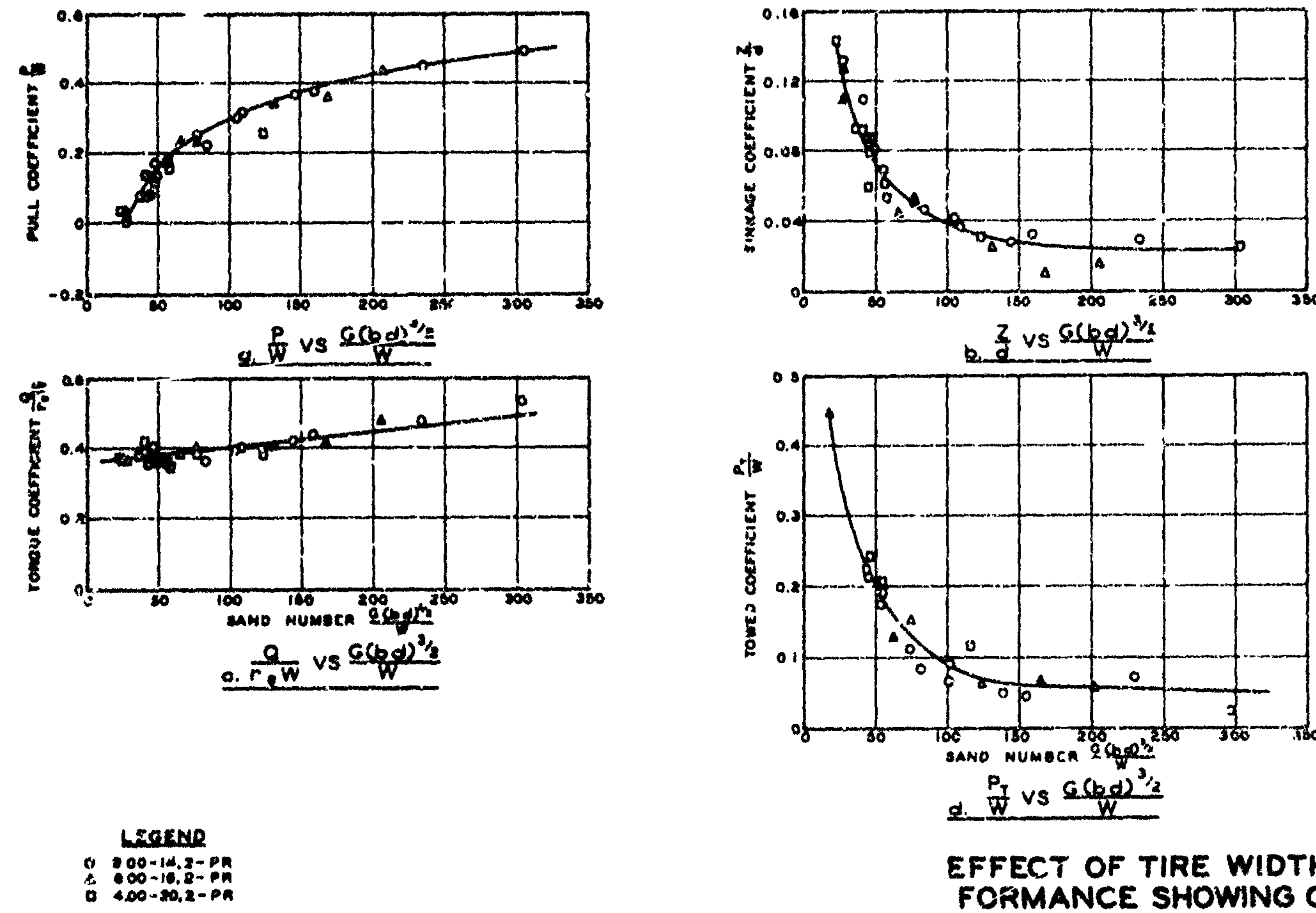


PULL COEFFICIENT $\frac{P}{W}$
a. $\frac{P}{W}$ VS $\frac{Gd^3}{W}$
SINKAGE COEFFICIENT $\frac{Z}{d}$
b. $\frac{Z}{d}$ VS $\frac{Gd^3}{W}$
TORQUE COEFFICIENT $\frac{Q}{r_e W}$
SAND LOADING NUMBER $\frac{Gd^3}{W}$
c. $\frac{Q}{r_e W}$ VS $\frac{Gd^3}{W}$
TOWED COEFFICIENT $\frac{P_T}{W}$
SAND LOADING NUMBER $\frac{Gd^3}{W}$
d. $\frac{P_T}{W}$ VS $\frac{Gd^3}{W}$
LEGEND
○ 9.00-14, 2-PR
△ 5.00-16, 2-PR
□ 4.00-20, 2-PR
EFFECT OF TIRE WIDTH
ON PERFORMANCE
35% DEFLECTION
THREE TIRES, 444- TO 3950-N LOAD
G=11 TO 60

PLATE 8

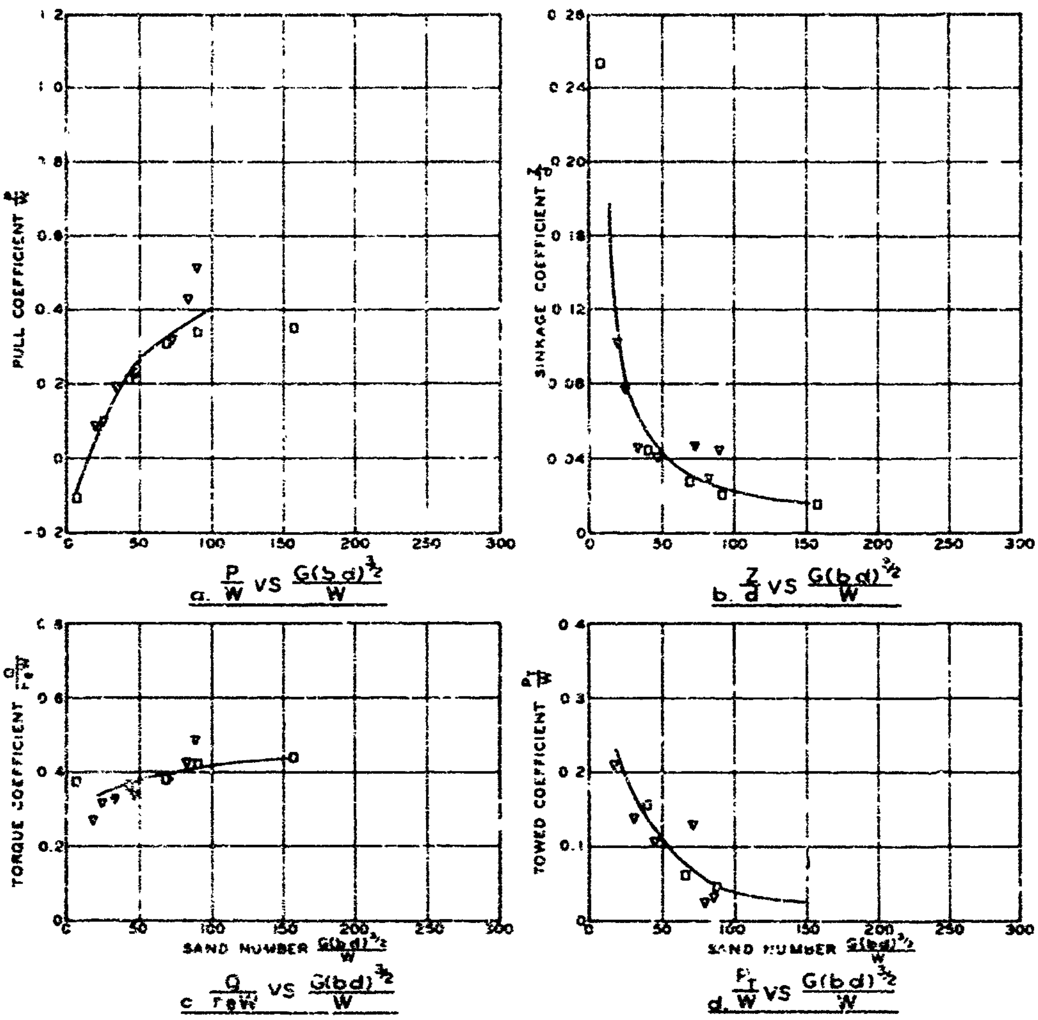


EFFECT OF TIRE WIDTH
ON PULL AND
SINKAGE COEFFICIENTS



EFFECT OF TIRE WIDTH ON PERFORMANCE SHOWING COLLAPSE OF DATA USING SAND NUMBER

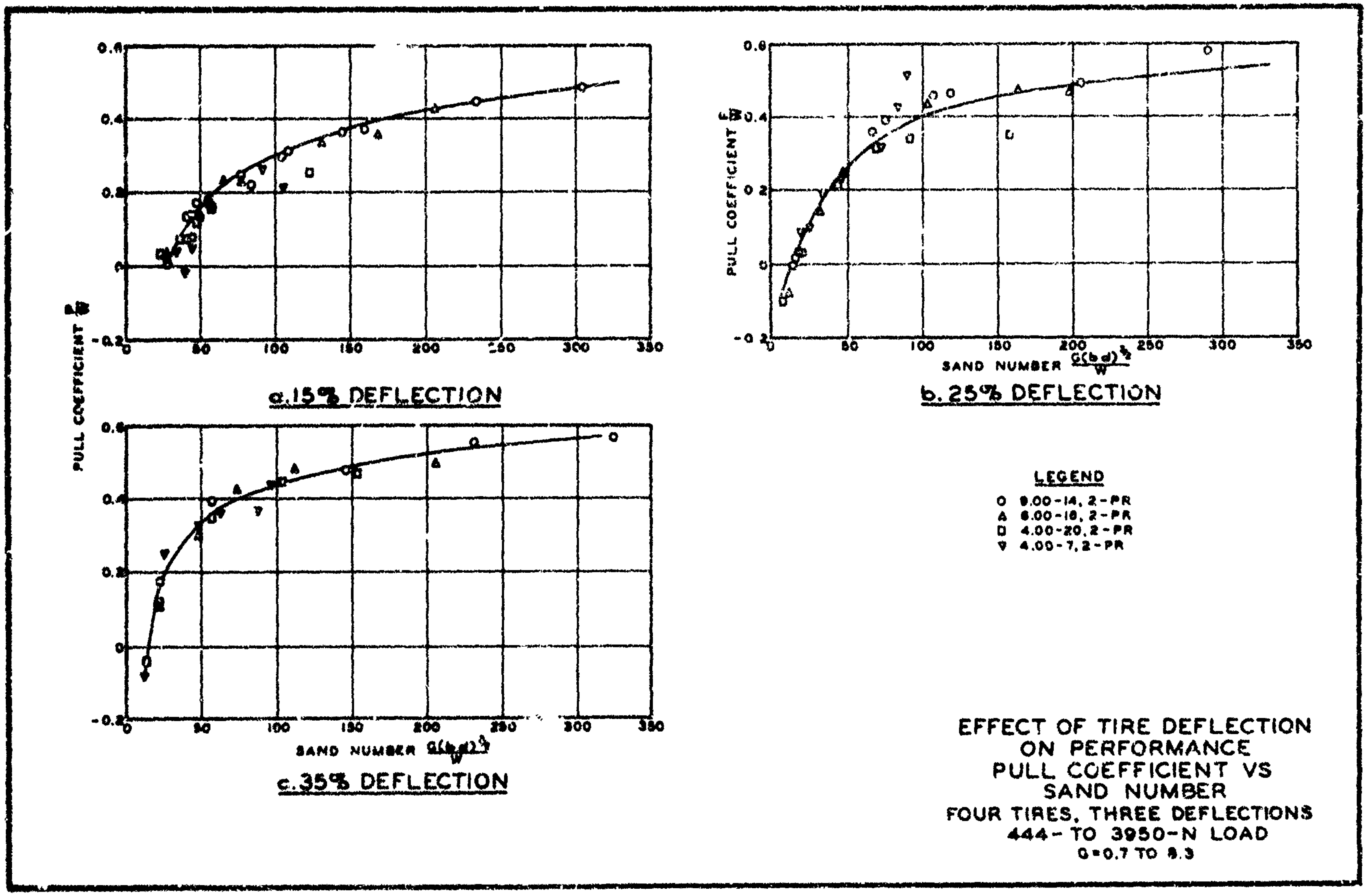
THREE TIRES, 15% DEFLECTION
444- TO 3950-N LOAD
G = 1.1 TO 8.0



LEGEND

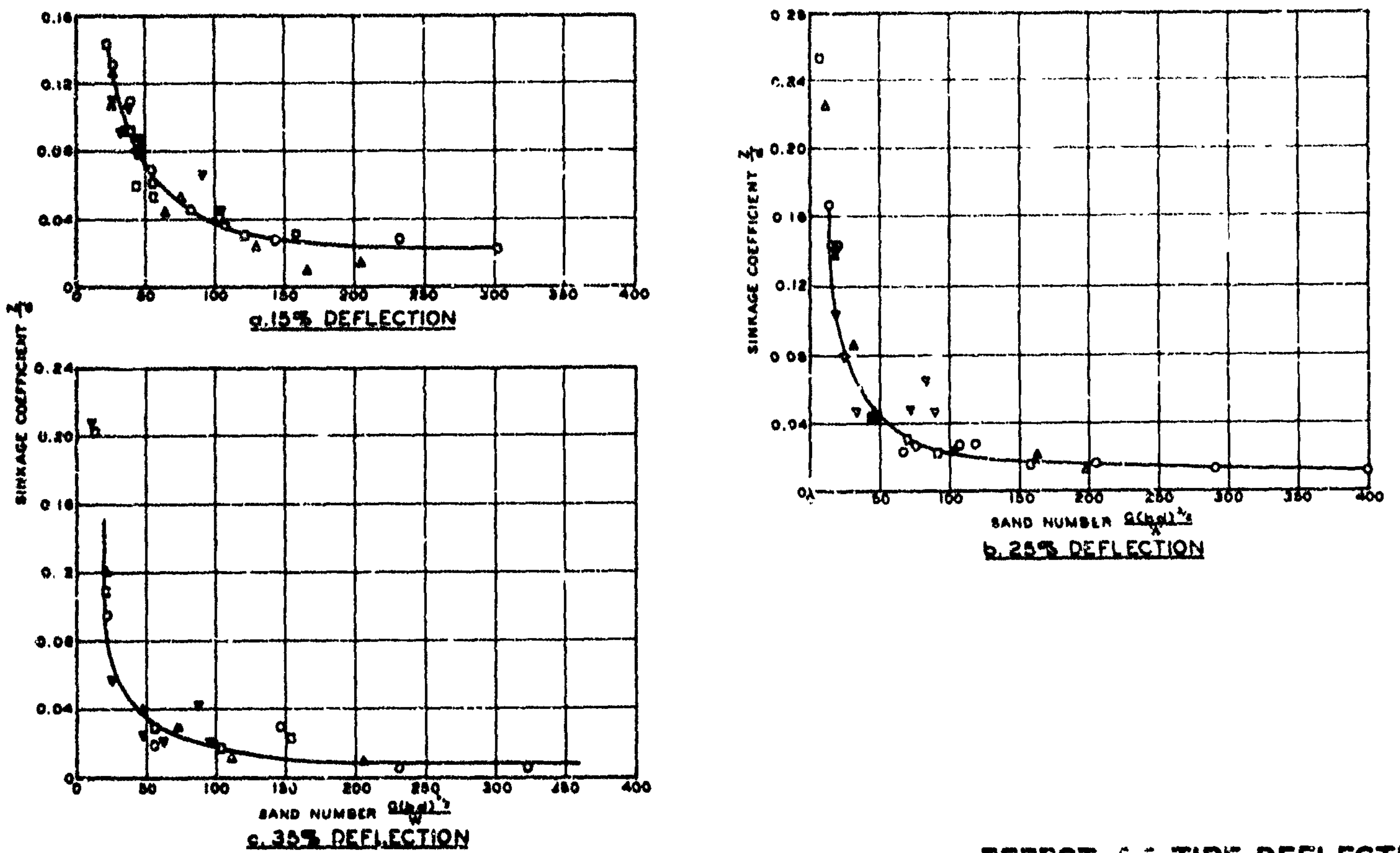
□ 4.00-20, 2-PR
▽ 4.00-7, 2-PR

EFFECT OF DIAMETER ON PERFORMANCE
4.00-20, 2-PR AND 4.00-7, 2-PR TIRES
25% DEFLECTION
444- TO 3950-N LOAD
G=0.9 TO 8.3



PULL COEFFICIENT P/W
SAND NUMBER G(bd)^(3/2)/W
a. 15% DEFLECTION
b. 25% DEFLECTION
c. 35% DEFLECTION
LEGEND
○ 9.00-14, 2-PR
△ 6.00-16, 2-PR
□ 4.00-20, 2-PR
▽ 4.00-7, 2-PR
EFFECT OF TIRE DEFLECTION
ON PERFORMANCE
PULL COEFFICIENT VS
SAND NUMBER
FOUR TIRES, THREE DEFLECTIONS
444- TO 3950-N LOAD
G=0.7 TO 8.3

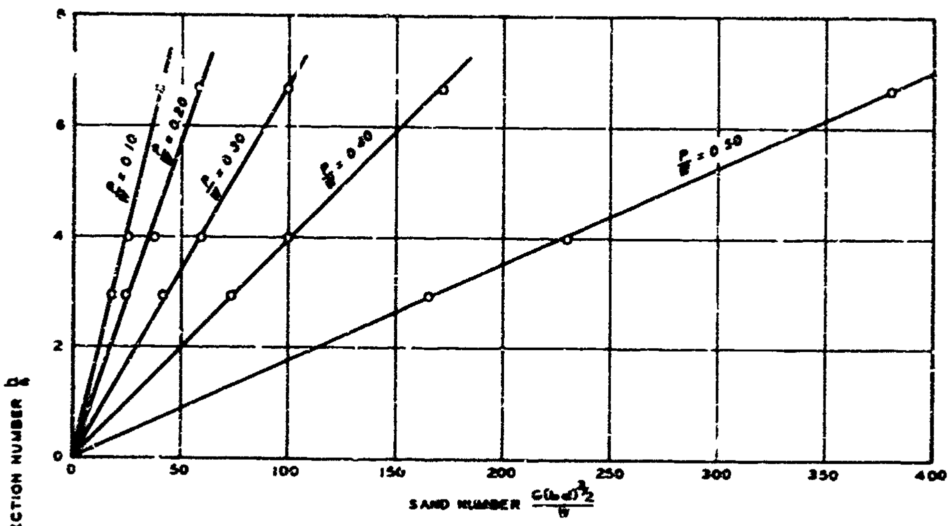
PLATE 12



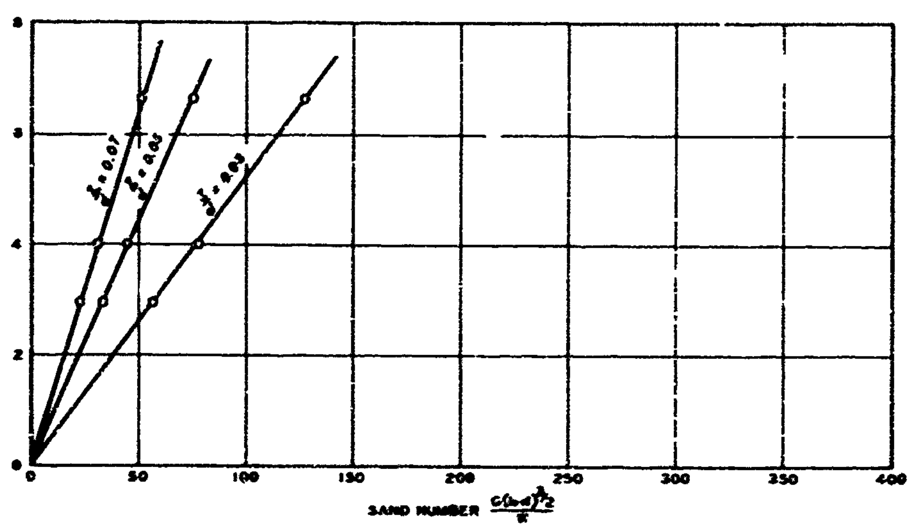
LEGEND
- O 9.00-14, 2-PR
- △ 6.00-16, 2-PR
- □ 4.00-20, 2-PR
- ▽ 4.00-7, 2-PR

EFFECT OF TIRE DEFLECTION ON PERFORMANCE, SINKAGE COEFFICIENT VS SAND NUMBER

FOUR TIRES, THREE DEFLECTIONS
444- TO 3950-N LOAD
G=0 7 TO 8.3



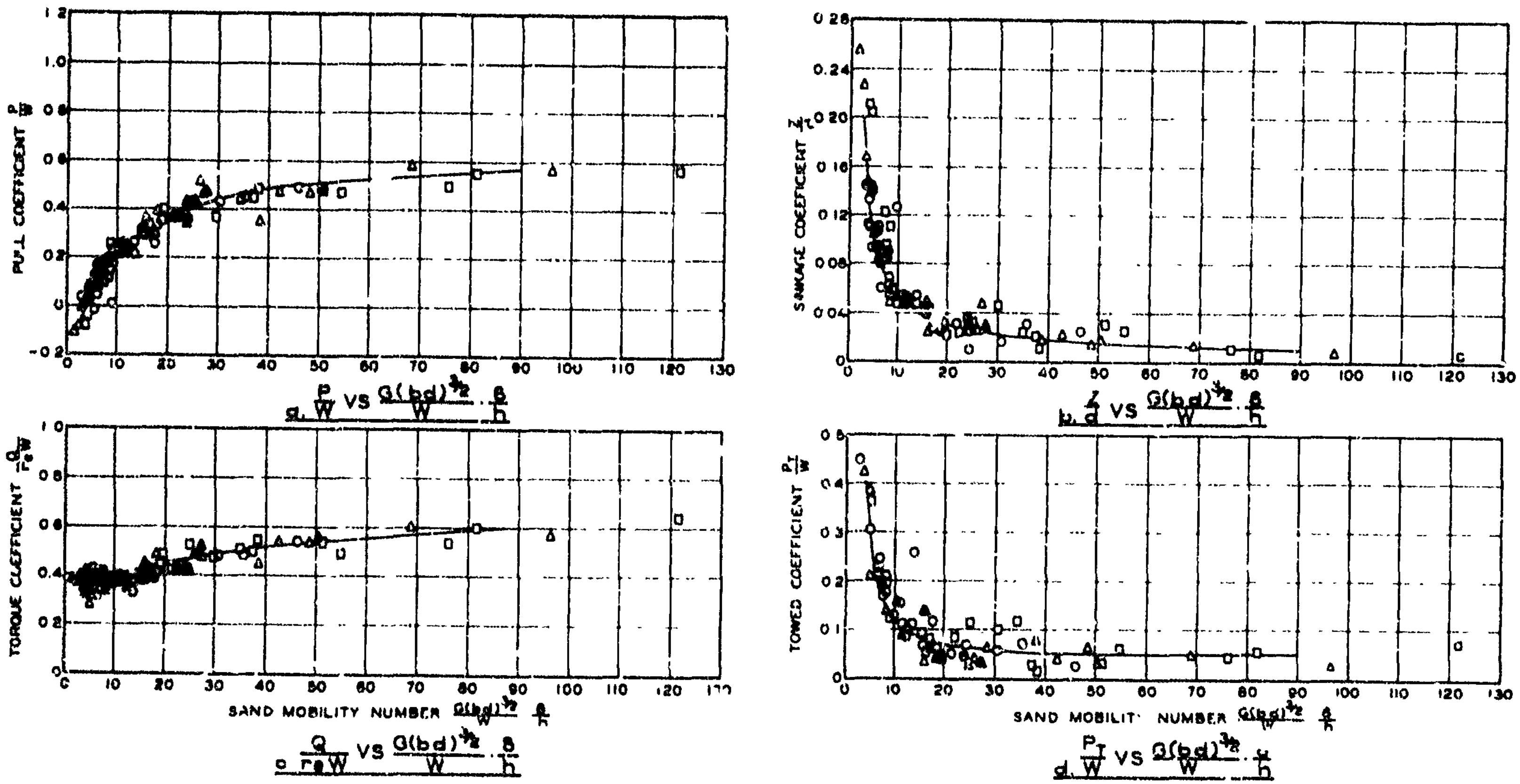
a. PULL COEFFICIENT



b. SINKAGE COEFFICIENT

SAND NUMBER VS RECIPROCAL OF DEFLECTION NUMBER PULL AND SINKAGE COEFFICIENTS

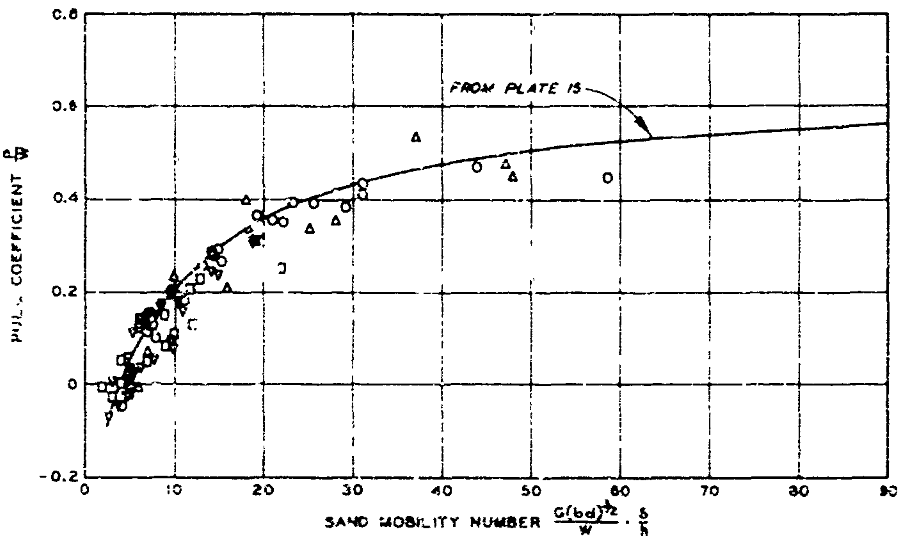
PLATE 14



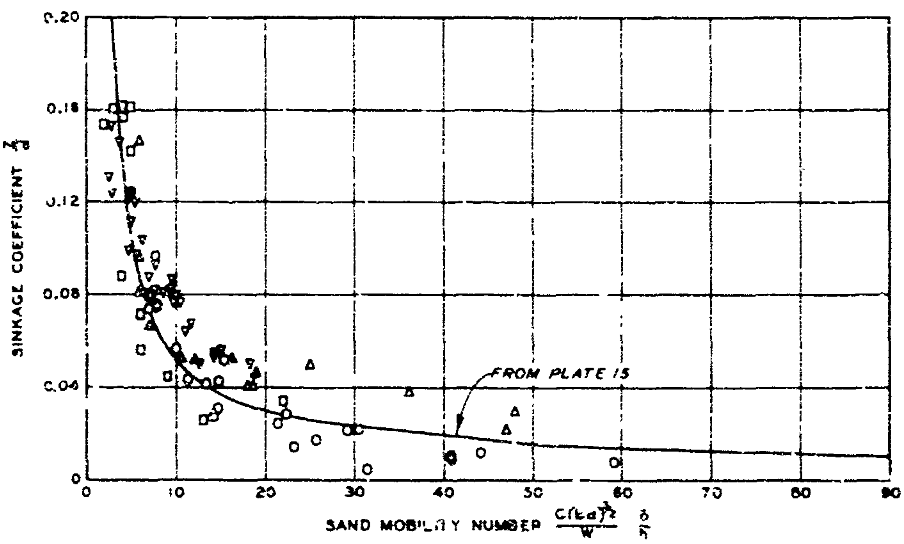
LEGEND

- O——O $\frac{\delta}{h} = 0.15$
- Δ——Δ $\frac{\delta}{h} = 0.25$
- □——□ $\frac{\delta}{h} = 0.35$

RELATION OF PERFORMANCE COEFFICIENTS TO SAND MOBILITY NUMBER
FOUR TIRES, THREE DEFLECTIONS
444- TO 3950-N LOAD
G = 0.7 TO 8.3



a. $\frac{P}{W}$ VS $\frac{G(bd)^{3/2}}{W}\cdot\frac{\delta}{h}$

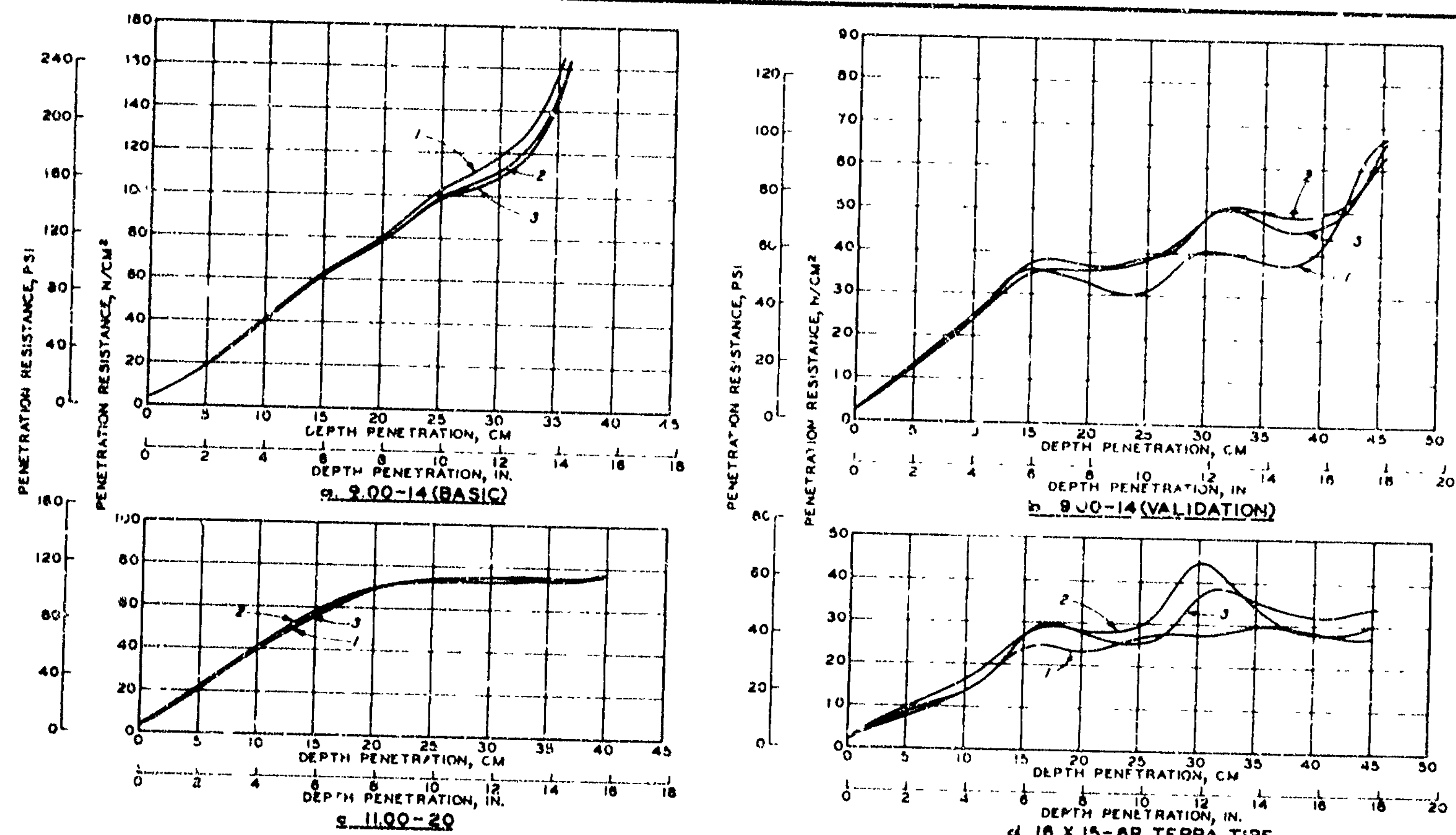


b. $\frac{Z}{d}$ VS $\frac{G(bd)^{3/2}}{W}\cdot\frac{\delta}{h}$

LEGEND

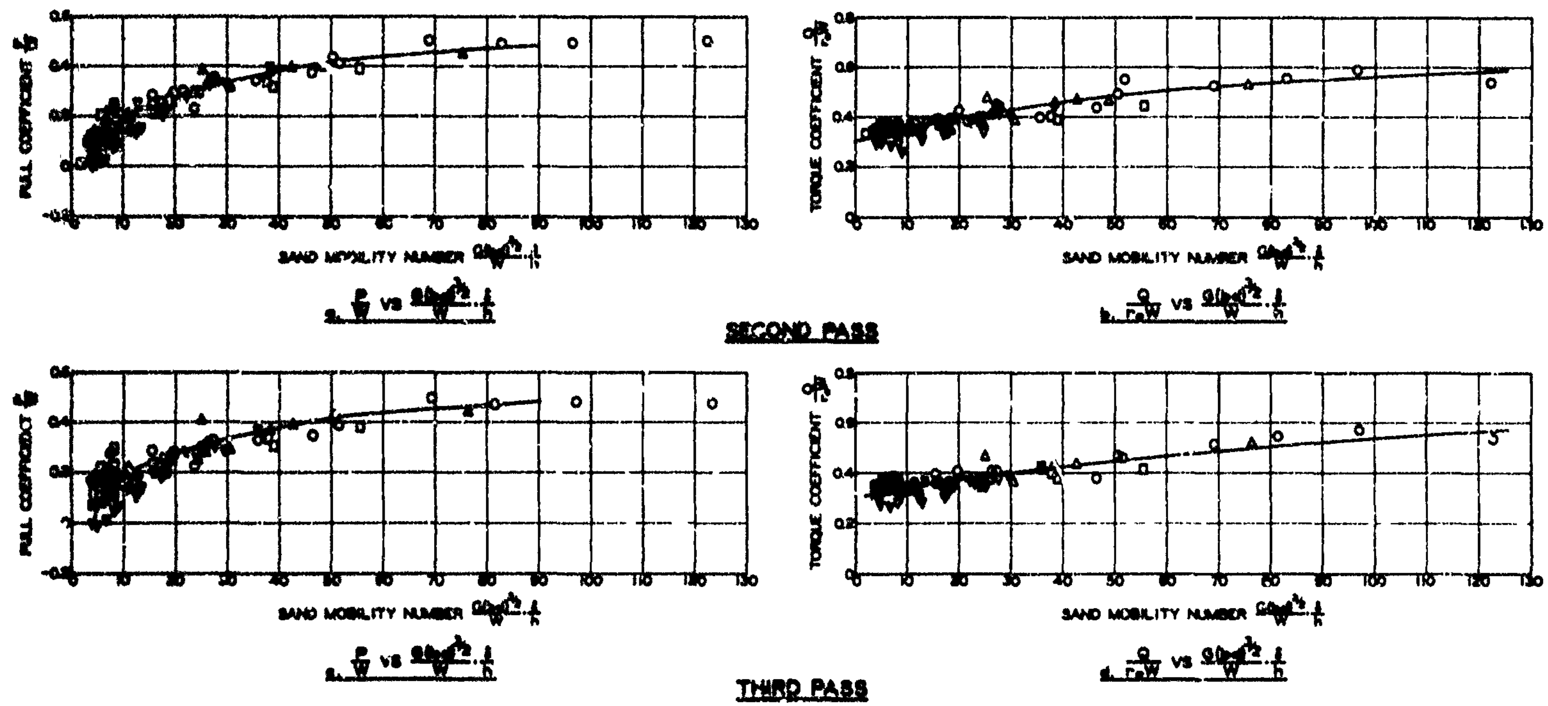
○ [illegible].00-14, 2-PR
△ 16 X 15-6R, 2-PR (TERRA TIRE)
□ 1.75-28, 2-PR (BICYCLE TIRE)
▽ 11.00-20, 2-PR

VALIDATION TEST DATA
FOUR TIRES, THREE DEFLECTIONS
444-TO 19,999-N LOAD
G = 1.0 TO 7.3



NOTE: NUMBERS ON CURVES REFER TO INDIVIDUAL PENETRATIONS AT DIFFERENT LOCATIONS IN THE TEST SECTION.

COMPARISON OF TYPICAL SOIL STRENGTH PROFILES



LEGEND

- ○ 9.00-14, 2-PR
- △ 6.00-16, 2-PR
- □ 4.00-20, 2-PR
- ▽ 4.00-7, 2-PR

MULTIPLE-PASS ANALYSIS SECOND AND THIRD PASSES

SOIL STRENGTH MEASURED BEFORE TRAFFIC

FOUR TIRES, THREE DEFLECTIONS
444- TO 3950-N LOAD
G = 0.7 TO 8.3

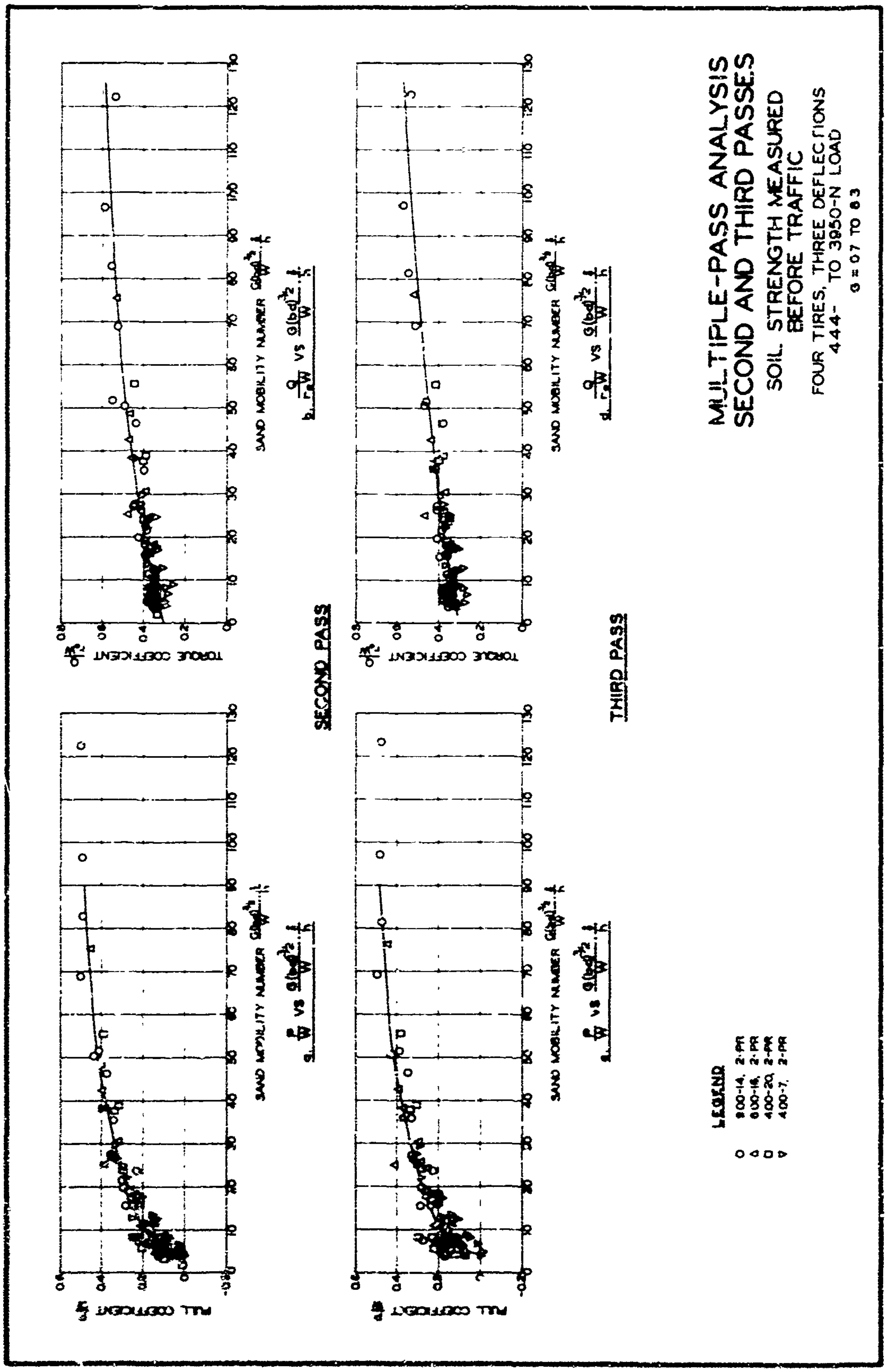
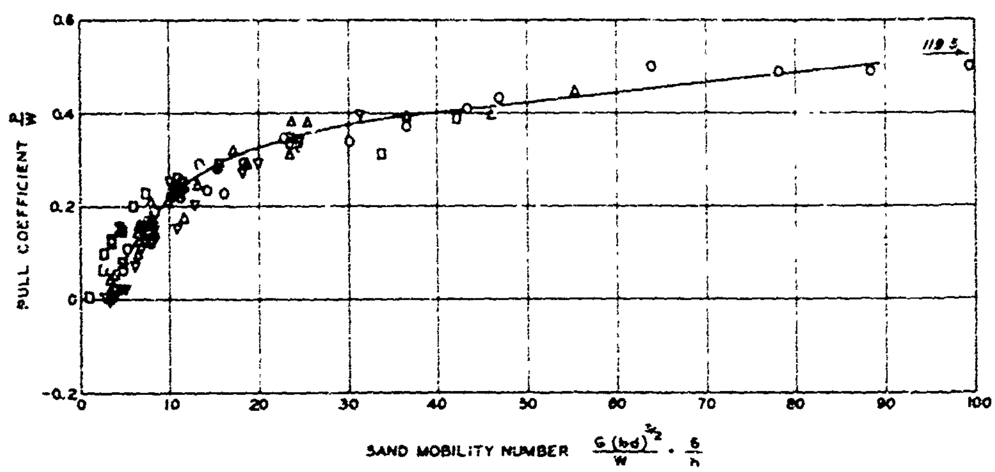
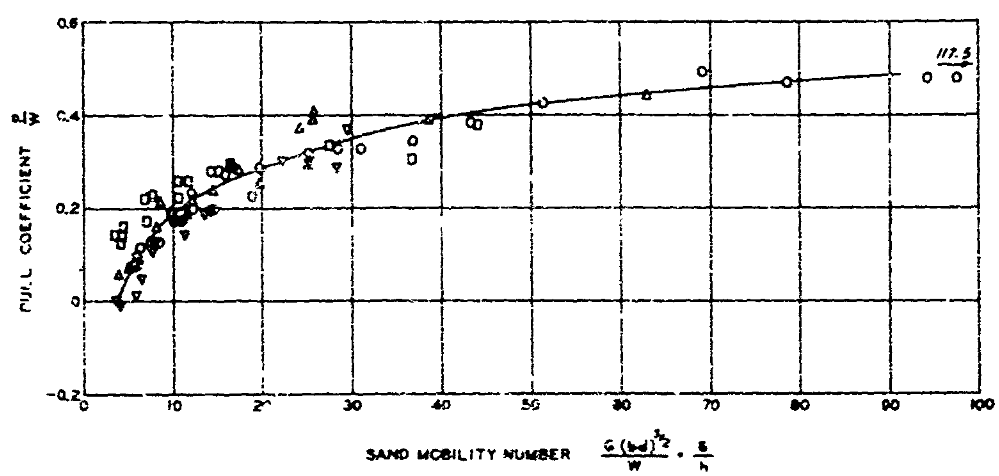

MULTIPLE-PASS ANALYSIS
SECOND AND THIRD PASSES
SOIL STRENGTH MEASURED BEFORE TRAFFIC
FOUR TIRES, THREE DEFLECTIONS, 444- TO 3950-N LOAD
SECOND PASS
THIRD PASS
PULL COEFFICIENT
TORQUE COEFFICIENT
SAND MOBILITY NUMBER
LEGEND
900-14, 2-PR
600-16, 2-PR
400-20, 2-PR
400-7, 2-PR

PLATE 18



a. SECOND PASS



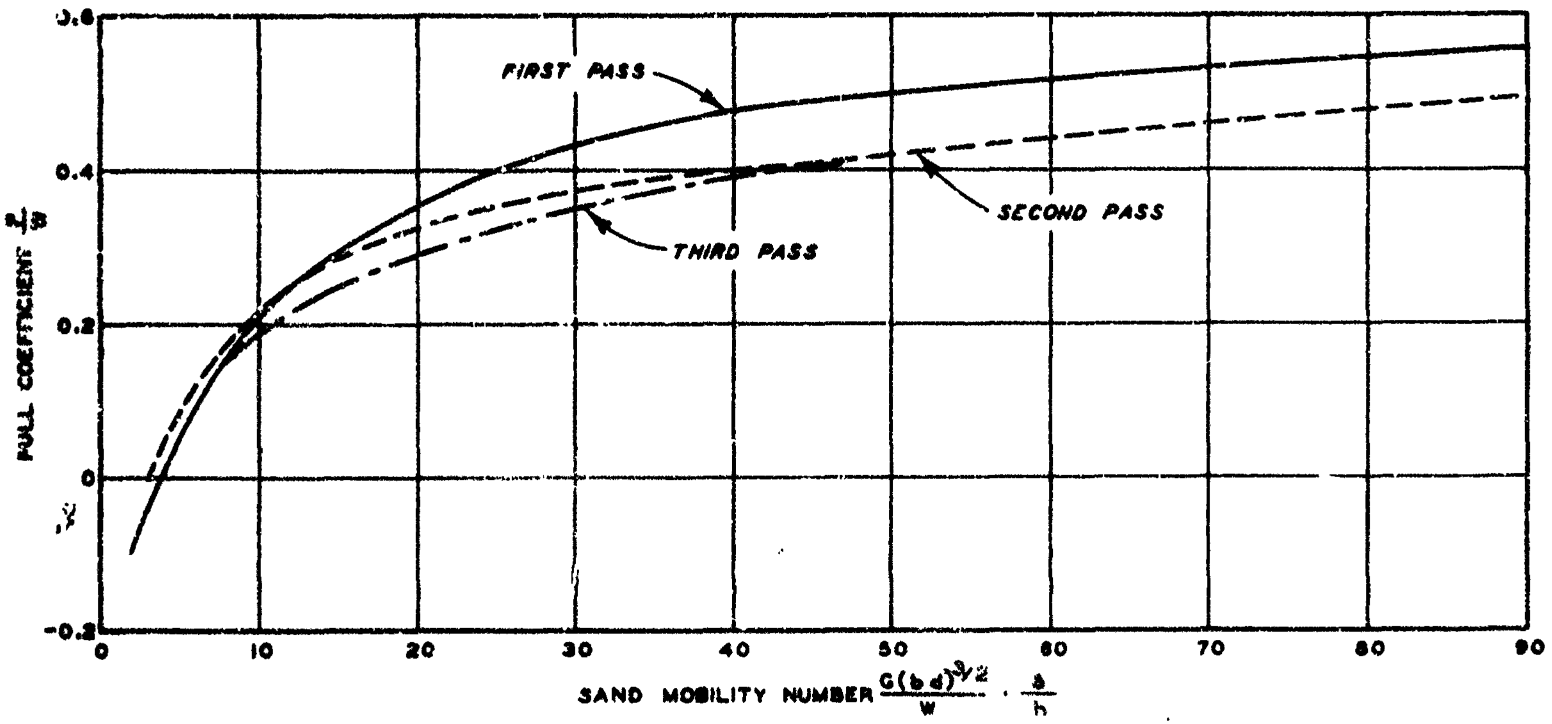
b. THIRD PASS

LEGEND
○ 9.00-14, 2-PR
△ 6.00-16, 2-PR
□ 4.00-20, 2-PR
▽ 4.00-7, 2-PR

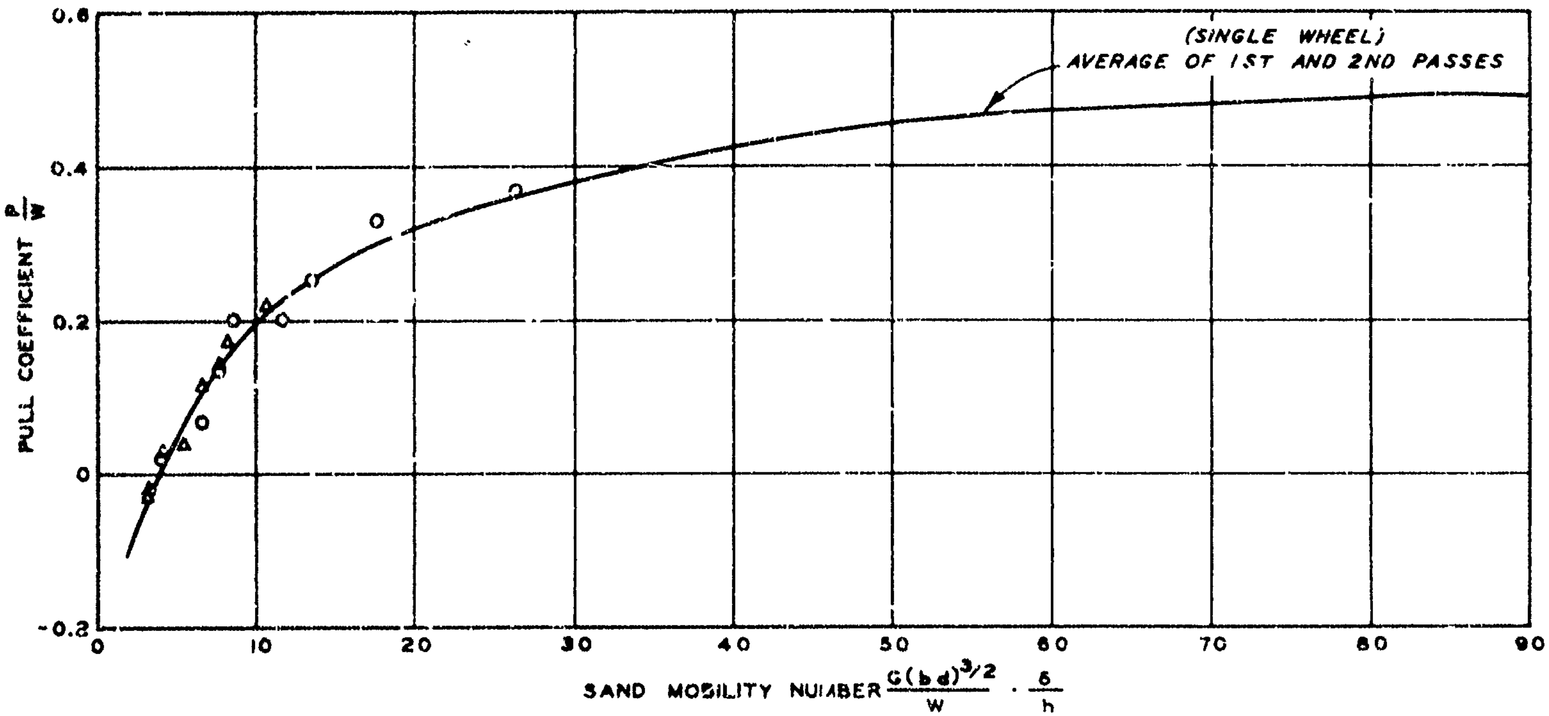
MULTIPLE-PASS ANALYSIS
SECOND AND THIRD PASSES

SOIL STRENGTH MEASURED
BEFORE EACH PASS

FOUR TIRES, 3 DEFLECTIONS
444- TO 3950-N LOAD
G=0.7 TO 7.2



MULTIPLE-PASS ANALYSIS
SUMMARY OF
FIRST THREE PASSES
SOIL STRENGTH MEASURED
BEFORE EACH PASS
FOUR TIRES, THREE DEFLECTIONS
444- TO 3950-N LOAD
G=0.7 TO 8.3



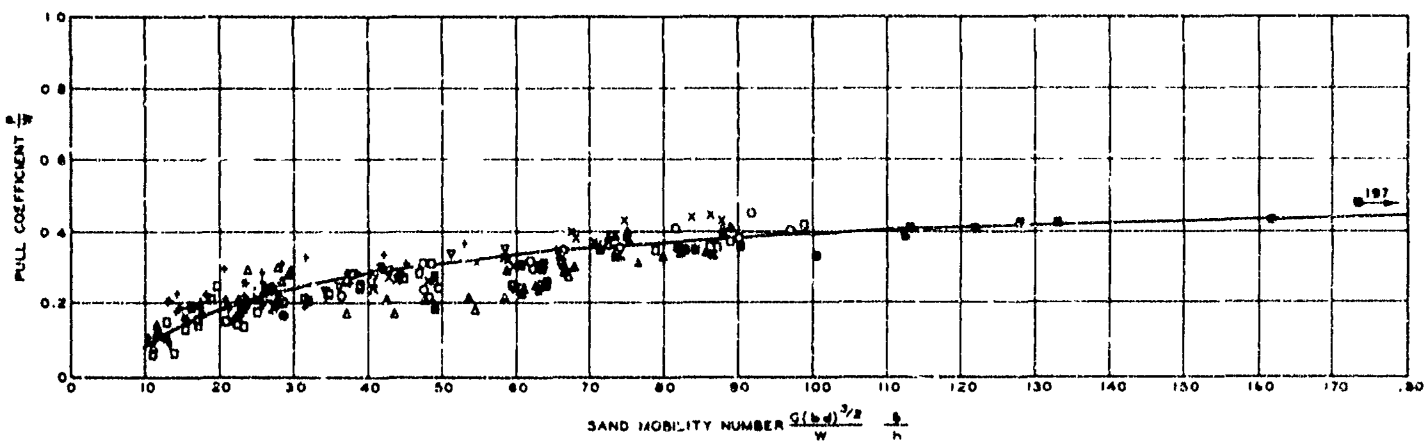
LEGEND

○ 9.00-14, 2-PR TIRES ON 4X4 TEST VEHICLE

△ 4.50-18, 4-PR TIRES ON 4X4 TEST VEHICLE

NOTE: G REPRESENTS SOIL STRENGTH BEFORE TRAFFIC

SINGLE-WHEEL AND FOUR-WHEEL-DRIVE VEHICLE PERFORMANCE LABORATORY TESTS

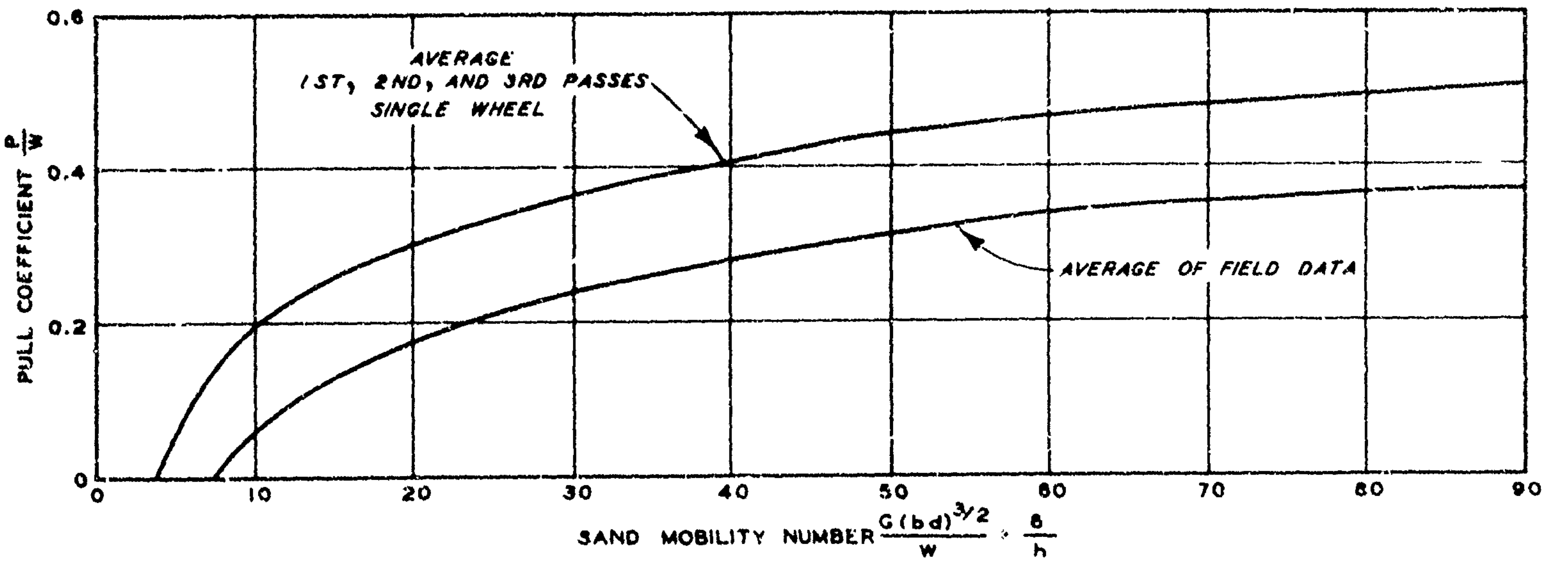


LEGEND

- O M38A1, 4X4 (JEEP)
- ▲ M37, 4X4 TRUCK, 3/4 - TON
- □ M34 AND M135, 6X6 TRUCKS, 2 1/2 - TON
- + DUKW 353, 6X6 TRUCK, 2 1/2 - TON
- ● M41, 6X6 TRUCK, 5-TON
- ▽ BUCKET LOADER, 4X4 TRACTOR
- △ TOURNADOZER, 4X4 TRACTOR
- X GOER, 4X4 CARGO CARRIER, 5-TON (18-26)
- ■ GOER, 4X4 CARGO CARRIER, 5-TON (15-34)

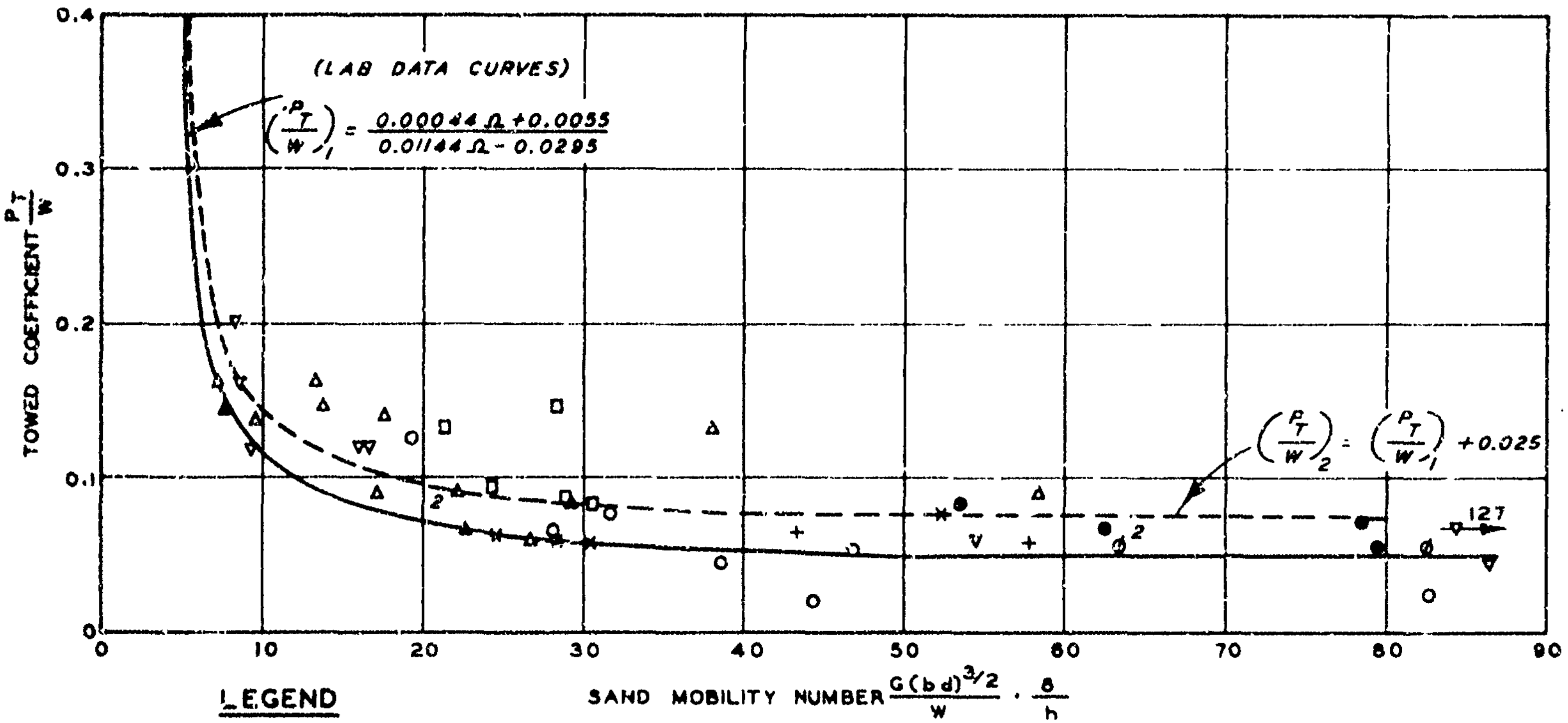
WHEELED VEHICLE PERFORMANCE IN SAND

FIELD TESTS



LABORATORY AND FIELD
PERFORMANCE DATA

	LAB	FIELD
WHEEL LOAD (N)	444-3,950	2,991-34,489
G	0.7-8.3	4-35
DEFLECTION (%)	0.15-0.35	0.09-0.43



LEGEND

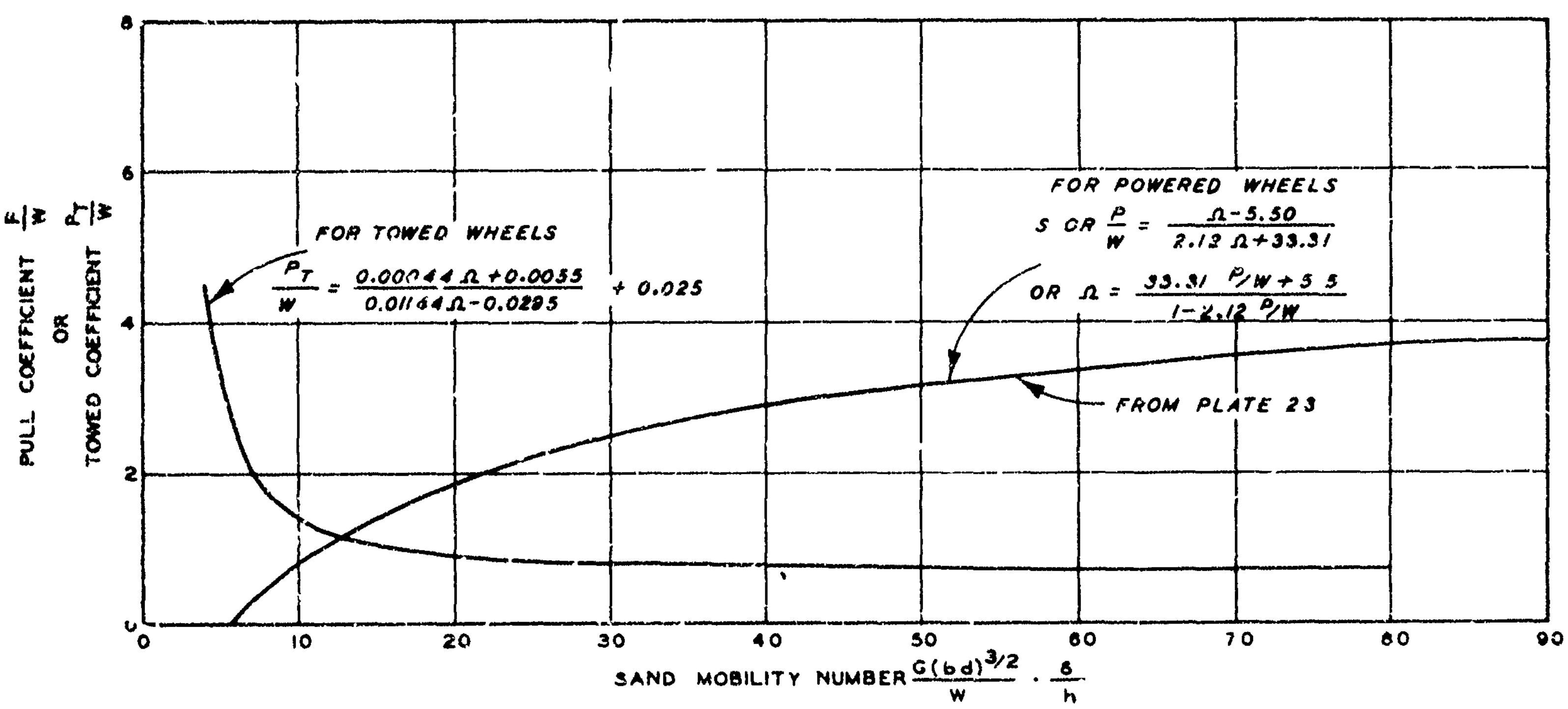
- O M37 (9-16)
- △ M135, 6X6 (11-20)
- ▲ M135, 4X4 (11-20)
- ▽ M41 (14-20)
- □ DUKW (11-16)
- ø GOER (15-34)
- \+ GOER (18-26)
- X BUCKET LOADER (14-24)
- ● TOURNADOZER (21-25)

NOTE: $\Omega = \frac{G(bd)^{3/2}}{W} \cdot \frac{\delta}{h}$

LABORATORY SINGLE-WHEEL AND FIELD VEHICLE TOWED COEFFICIENTS

DRY TO MOIST SAND

	LAB	FIELD
WHEEL LOAD (N)	444-3,950	7,935-34,489
G	0.7-8.3	2-34
DEFLECTION (%)	0.13-0.35	0.10-0.38



NOTE: $\Omega = \frac{G(bd)^{3/2}}{W}\ \frac{\delta}{h}$

PERFORMANCE PREDICTION CURVES FOR WHEELED VEHICLES IN SAND

PLATE 26